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Evaluating Uranium Depth Versus Socio-Economic Statistics for Residential Radon Vulnerability in Warren County, Kentucky

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EVALUATING URANIUM DEPTH VERSUS SOCIO-ECONOMIC STATISTICS FOR RESIDENTIAL RADON VULNERABILITY IN WARREN COUNTY, KENTUCKY.

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Anthony Joseph Iovanna October 1, 2004 88 Pages

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ABSTRACT

Residences in Warren County, Kentucky, are characterized by high levels of residential radon, which is one of the radioactive daughter products of uranium. According to the United States Environmental Protection Agency (US EPA), radon exposure causes approximately 22,000 lung cancer deaths in the United States per year. The City of Bowling Green, in Warren County, is underlain by karst, an easily soluble limestone subsurface, which allows radon gas to travel easily through cracks and fissures. Carbonate rocks under Bowling Green are underlain by the Devonian Chattanooga Shale, a low-grade uranium ore and a potential source of radon gas. A digital map of the Chattanooga Shale was created using Arc GIS. A 1.6 km by 1.6 km (one-mile by one-mile) grid for Warren County was generated, and depth data from oil wells within each grid cell were averaged to render the elevation of the top surface of the Chattanooga Shale in a digital format. A socio-economic GIS of Warren County was created using US Census Bureau and Property Value Administration data. The Chattanooga Shale and the socio-economic layers were correlated to test points that have high residential radon measurements to determine whether proximity to the shale layer or home type is the better predictor for radon risk. Once risks have been determined, management decision-making is simplified and resources can be targeted towards high need areas. Although this study determined that home type, i.e., size of the home and whether there is a basement present, does have a significant effect on residential radon levels, proximity to the top surface of the Chattanooga Shale does not have a significant effect in Warren County, Kentucky. Due to this lack of a geologic pattern it is recommended that radon mitigation systems be included in all new home construction and design.

Key Words: Radon, Karst, Environmental Policy, Public Health, GIS

Introduction

In recent decades, there has been an increased emphasis in the geosciences on studying how human activity affects the natural world. Some current human-environment interaction issues include water and air pollution, ozone depletion, global climate change, radon pollution, acid rain, acid rock drainage, erosion, soil degradation, deforestation, and desertification. The relationship between humans and the environment has become of heightened interest, in part, due to the increase in human populations worldwide. Research on these environmental issues and mitigation processes can lead to policy changes that are designed to minimize the impact of humans. Karst is an environmentally complex landscape type and provides an excellent example of human-environment interactions.

Karst makes up a significant portion of the Earth's land surface, and there is little understanding of its environmental limitations for development. People fail to recognize the special risks and opportunities that are associated with karst landscapes. According to Veni et al. (2001) there are several major cities in the United States located on karst: St. Louis, Missouri; Nashville, Tennessee; Birmingham, Alabama; Austin, Texas; Knoxville, Tennessee; Orlando, Florida; Huntsville, Alabama, etc. Approximately twenty percent of the United States is karst, with significant formations occurring in at least twenty states.

There are many environmental concerns linked to human development on karst. One of these concerns is increased levels of indoor radon (Webster, 1990). Radon is a colorless, odorless gas that occurs naturally in the environment attributable to the radioactive decay of uranium. Radon is a threat when it becomes trapped and concentrated indoors and is subsequently inhaled into the lungs. As a result of this inhalation, radon gas causes cancer and is the second leading cause of lung cancer after cigarette smoking. Radon can be found throughout the world. However, karst is conducive to the concentration and subsequent upward percolation of radon gas from the subsurface to the surface through fractures, and ultimately in the basements of homes. The research area examined in this investigation was Warren County, Kentucky (Figure 1).

This study examined the physical attributes of homes (i.e., the square area, and whether there was a basement present in the home) that were tested for radon using a continuous flow monitor. These characteristics are hypothesized in this study to affect the amount of radon present in homes. The relationships between the potential source of the radon, a shale layer, and the test point locations were examined. After these factors were investigated, the probability of certain categories of homes having higher levels of radon was determined.

This research hypothesizes that dangerously high levels of indoor radon pollution in the area of Warren County, Kentucky do not follow the expected geological pattern. The expected pattern is for radon test points with the closest proximity to the geologic source of uranium, and subsequently radon, to have the highest radon levels.

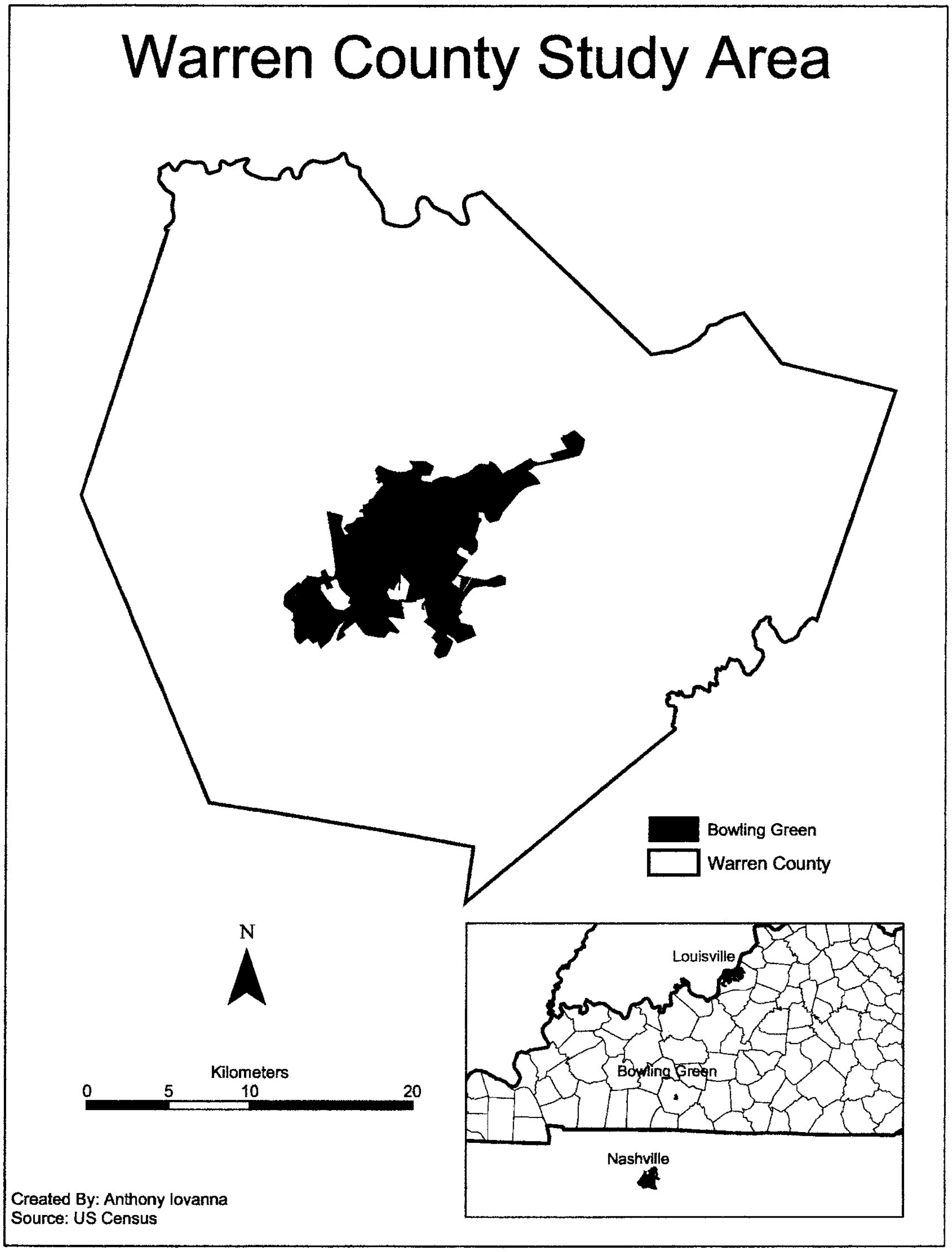


Figure 1: Warren County, Kentucky, and the City Limits of Bowling Green.
Source: US Census Bureau (2000)

Chapter One

Background

Radon is the second leading cause of lung cancer, and is implicated in more deaths per year than drunken driving (Figure 2) (US EPA, 1992). Sullivan et al. (1997) and Kerr (1988) stated that 5,000 to 20,000 people die each year due to radon exposure. Conrath and Kolb (1995) stated a range of 7,000 to 30,000 people per year, and Smith (2001) defined a range of 3,000 to 41,000 deaths per year that could be attributed to radon. This range of numbers is large because it is difficult to determine if radon is the primary cause for a particular case of lung cancer. Radon could be one cause among many, such as cigarette smoking and exposure to asbestos. Although this range is a significant one, it seems apparent that a large number of people die each year from lung cancer caused by radon exposure.

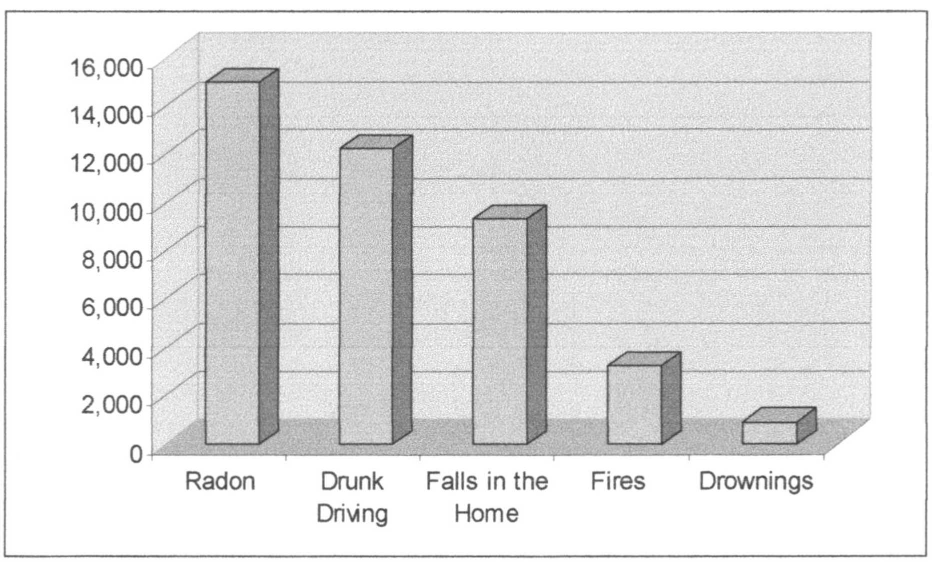


Figure 2: Number of radon deaths compared to other fatalities. The US Environmental Protection Agency states that at least 15,000 lung cancer deaths each year can be attributed to radon.
Source: US Environmental Protection Agency (US EPA 1992)

Radon gas is present throughout the United States, but is concentrated in the north and northeastern (Appalachian) regions as well as the upper Midwest and the Rocky Mountain areas of the United States. This radon risk is shown in the US Environmental Protection Agency (US EPA) radon risk map of the United States (Figure 3) (US EPA, 1992). The US EPA also produced a map showing the risk of radon in the state of Kentucky as well (Figure 4) (US EPA, 1992).

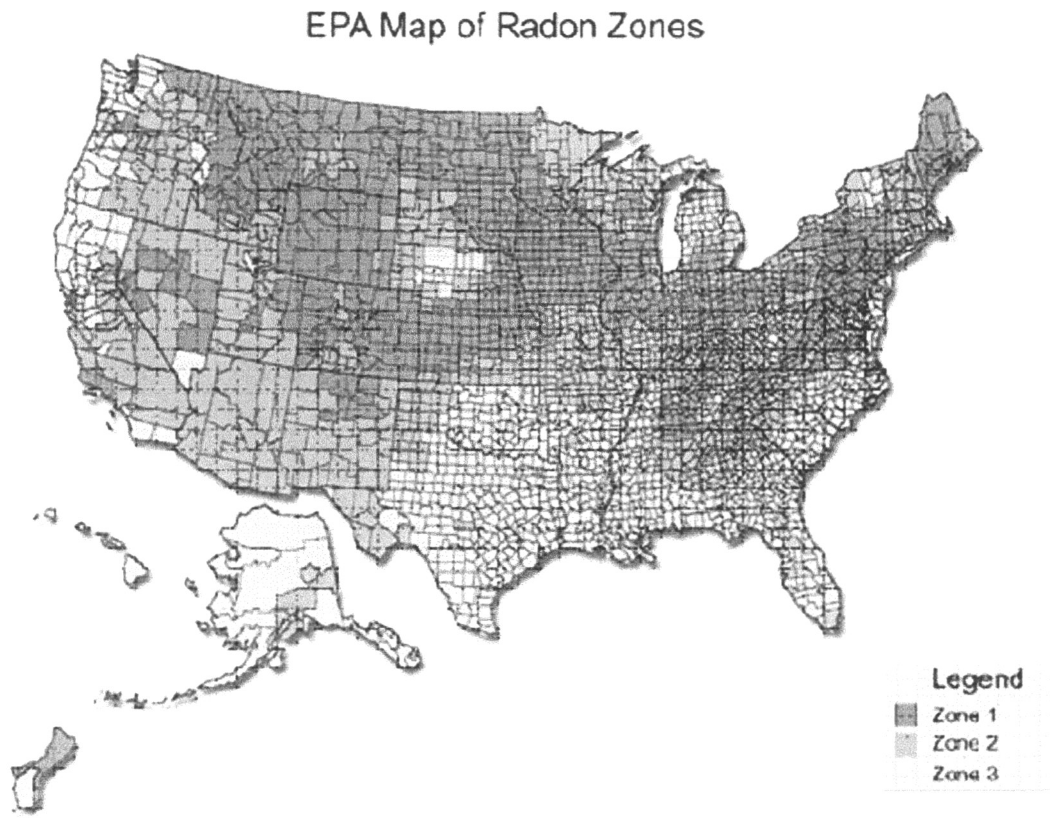


Figure 3: Radon risk map for the United States. Dark gray (Zone 1) is the highest risk, medium gray (Zone 2) is moderate risk and light gray (Zone 3) is the lowest risk.
Source: US Environmental Protection Agency (EPA 1992)

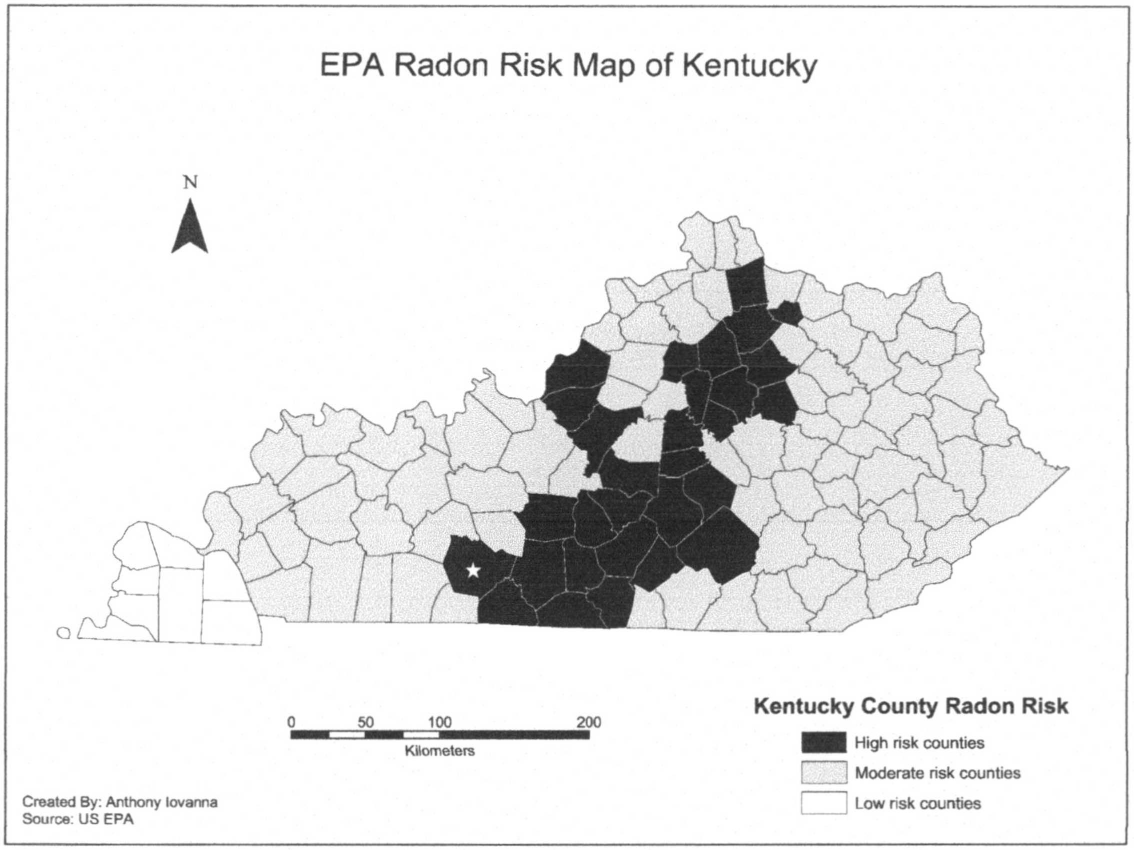


Figure 4: Radon risk map for Kentucky. Black is the highest risk, gray is moderate risk and white is the lowest risk. Warren County is located in zone one, the highest risk area. The star shows Warren County. **Source:** US Environmental Protection Agency (EPA 1992)

The study of indoor radon is beneficial because the public can be informed of the public health danger from radon gas. If individuals understand the risk factors associated with elevated radon gas levels, they could better determine if mitigation is needed for their residence. Mitigation is both inexpensive and simple as illustrated in Chapter Two.

Radon is measured in picocuries (pCi). Picocuries express the amount of radioactivity present in radon. A picocurie is one-trillionth of a curie (10^{-12}). A curie is a method of measuring the amount of radioactivity present. Typical measurements of radon gas in the outdoor air measure less than 0.1 pCi/l, while measurements in water have been measured as high as three million pCi/l (US EPA, 1992). Aeration of water containing three million pCi/l of radon in water results in three hundred pCi/l in the atmosphere. Radon in water should be a worry if the primary source of drinking water is from untreated ground water or if water is present in the basement or caves. The US Environmental Protection Agency (US EPA) has set the atmospheric radon action level at 4 pCi/l (US EPA, 1992). If a home is at or above this level, the US EPA recommends that the home be mitigated.

Radon is a radioactive gas that results from the decay series of uranium 238. The types of decay and decay products are shown on Table 1. During this process, the atomic number and/or atomic mass change, resulting in the element being altered so that a new element or "daughter" is formed. Alpha, beta, and gamma ray emissions are the three principle types of radioactive decay.

Alpha particles contain two protons and two neutrons. These particles travel very fast but are weak and can be effectively blocked by a sheet of paper, due to their relatively large size. Beta particles are electrons from the atomic nucleus and have a greater penetrating ability than alpha particles. Gamma rays are not particles. They are short wavelength photons that have high penetrating power.

Uranium 238 indirectly decays to radium 226. Radium 226 emits two alpha particles and decays to radon 222. Radon 222 emits two alpha particles and decays to polonium 218. The half-life of radon is only 3.825 days (Environmental Chemistry, 2004). The half-life is the amount of time it takes for one half of the atoms of an unstable element to decay radioactively to produce another element.

Uranium 238 Decay Table			
Parent Isotope	Half Life	Decay Type	Principle Daughter Isotope
Uranium 238	4.5 X 10EE9 years	Alpha, Gamma	Thorium 234
Thorium 234	24.1 days	Beta, Gamma	Protactinium 234
Protactinium 234	1.17 minutes	Beta, Gamma	Uranium 234
Uranium 234	2.44 X 10EE5 years	Alpha, Gamma	Thorium 230
Thorium 230	7.7 X 10EE4 years	Alpha, Gamma	Radium 226
Radium 226	1.6 X 10EE3 years	Alpha, Gamma	Radon 222
Radon 222	3.82 days	Alpha, Gamma	Polonium 218
Polonium 218	3.05 minutes	Alpha	Lead 214
Lead 214	26.8 minutes	Beta, Gamma	Bismuth 214
Bismuth 214	19.8 minutes	Beta, Gamma	Polonium 214
Polonium 214	1.64 X 10EE-4 seconds	Alpha, Gamma	Lead 210
Lead 210	22.3 years	Beta, Gamma	Bismuth 210
Bismuth 210	5.01 days	Beta	Polonium 210
Polonium 210	138.4 days	Alpha, Gamma	Lead 206
Lead 206	Stable		

Table 1: Uranium Decay Table. Radon is one of the decay products of uranium 238 and decays directly from radium 226. Radon 222 is between Radium 226 and Polonium 218.
Source: Modified from The North Carolina Chapter of the Health Physics Society Science Teacher's Workshop (Retrieved on 9/30/04)

Uranium is found naturally throughout the world, in a variety of rock types including high silica igneous rocks, black shale, and metamorphic rocks. The presence of these types of rocks points to a high potential for radon (Montgomery, 1997). One of these shales that contain high levels of uranium is the Chattanooga Shale (Figure 5), which is also known as the Black Shale and the New Albany Shale. The Chattanooga Shale is located in Arkansas, Tennessee, Missouri, Oklahoma, Ohio, Kentucky, Indiana, and Illinois (Landis and Swanson, 1962; Montgomery, 1997). The Chattanooga Shale is the presumed uranium source for radon in Warren County (Deming, 2000, Montgomery, 1997, and the USGS, 1997). However, Crawford and Webster (1989; 1990) and Webster (1990) after an investigation of radon levels in homes and caves in Bowling Green, concluded that the source of radon was not the Chattanooga Shale. The United States Geological Survey (USGS, 1997) states the Chattanooga Shale, in the southeastern United States, generally contains between ten to eighty-five parts per million (ppm) of uranium. The Chattanooga Shale near Nashville, Tennessee, contains between 250 and 350 ppm of uranium (Landis and Swanson, 1962). Samples of the Shale were also taken from Arkansas, Oklahoma, and Missouri and tested for their uranium content by Landis and Swanson (1962), and these samples contained 20-30 ppm uranium. The variation in the Chattanooga Shale uranium content shows potential variability that could be examined in future studies.

Figure 5: Picture of a segment of the Chattanooga Shale from near Nashville Tennessee. It is brown where it has been weathered and black on the inside. If the shale is broken, it has a petroleum odor.

Study Area

The study area of Warren County, Kentucky is located on the Pennyroyal Plain in the south central part of the state (Crawford, 2001; Jillson, 1928). This area is a karst landscape, which forms in Mississippian Limestones. It is characterized by the presence of caves, sinkholes, fractures, and the absence of abundant surface water flows (Figure 6). Figure 7 also shows how fissures provide connections from caves to the surface in a karst landscape. There are three units of Mississippian age limestone that underlie Warren County. The three units in descending order from the youngest to the oldest are Girkin, Ste. Genevieve, and St. Louis Limestones (Crawford, 2001; Jillson, 1931; McFarlan, 1950). The St. Louis and Ste. Genevieve Limestone underlie the County, and the hills that rise above the landscape are primarily Girkin Limestone (Crawford, 2001). These limestones are in turn underlain by the Salem and Warsaw Limestones and the Fort Payne Formation. Below the Fort Payne is the Devonian Chattanooga Shale (Jillson, 1931; McFarlan, 1950).

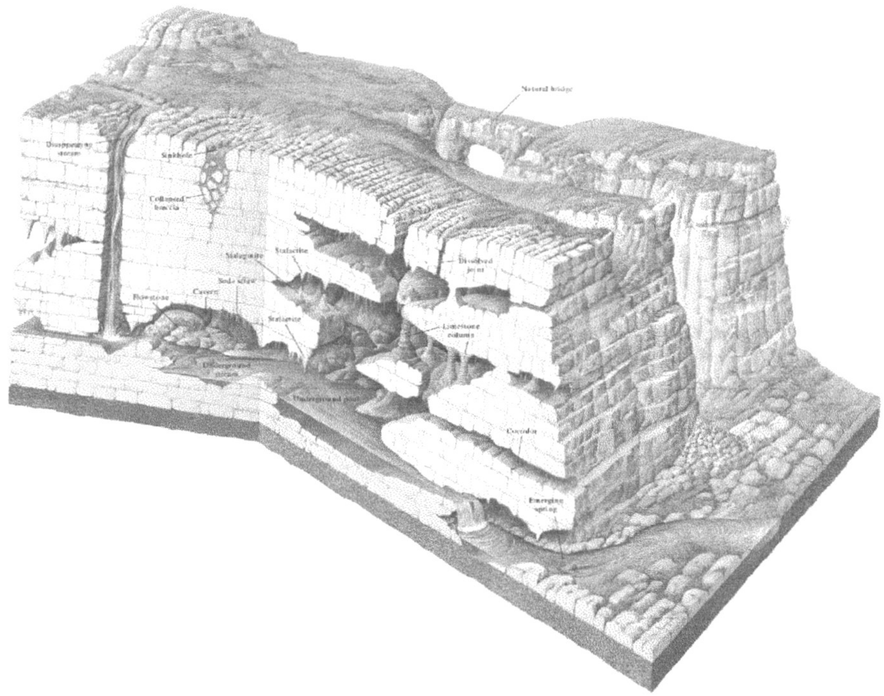


Figure 6: Diagram of karst landscape. This diagram shows the features of a karst landscape, such as sinking streams, underground streams, sinkholes, caves, and fissures. It is because of open chambers, and fissures beneath this type of landscape that radon can reach the surface within its half-life.
Source: Marshak p.602-603 (2001)

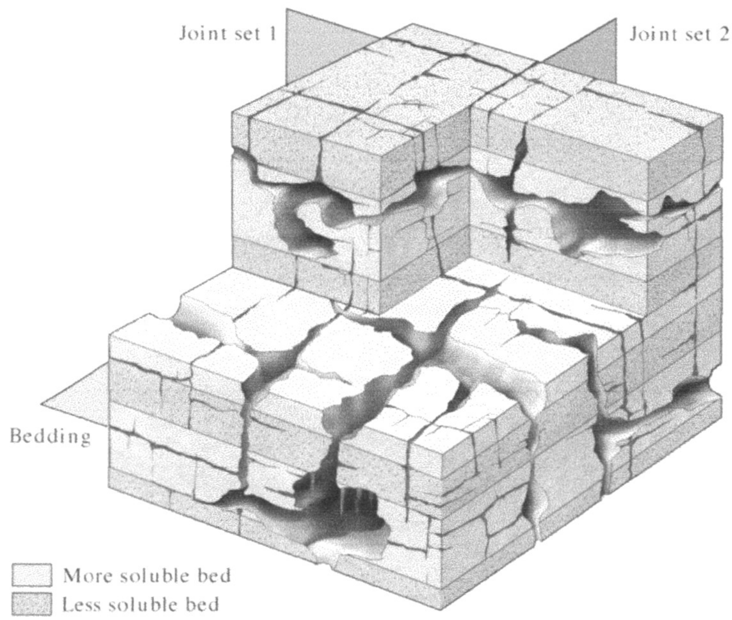


Figure 7: Diagram of karst showing fissures that connect caves and create passage for radon to quickly move from the Chattanooga Shale layer to the surface.
Source: Marshak p.604 (2001)

Webster (1990) and the US EPA (1987) both recorded high levels of indoor radon. The EPA, in 1987, found that forty-six percent of Bowling Green homes measured had radon levels that equaled or exceeded 4 pCi/l. Webster recorded the mean radon levels of homes with basements was 22.92 pCi/l, and the mean for homes without basements was 4.73 pCi/l.

It is hypothesized in this study that characteristics of the limestone allow radon to travel quickly from the Shale layer to the surface, and into homes. Cracks and fissures present in the limestone act as conduits for radon to travel to the surface before its half-life of 3.82 days has elapsed (Figure 7). Although radon is traveling to the surface quickly, it must still enter homes. Radon can enter into homes through cracks in the foundation, construction joints where foundation walls and the foundation floor come together, loose-fitting pipe penetrations into the home, sump-pump wells, pores in the foundation wells, and water (Teichman, 1998; Viera, 2000).

Procedures

The Chattanooga Shale was determined to be a potential source of uranium in Warren County through testing by Deming (2000), Landis and Swanson (1962), Montgomery (1997), Nininger (1956), and the USGS (1997). It is hypothesized in this study that the vertical proximity of homes to the Shale should not have an effect on the levels of radon in homes. To determine if homes closest to the Shale had the highest radon levels, the depth of the Chattanooga Shale below the surface of Warren County was determined by using Oil and Gas Well data from the Kentucky Geological Survey

(KGS). This shale depth map showed the average depth from the surface to the top of the Chattanooga Shale.

Oil-drilling logs were used to determine the depth of the Chattanooga Shale below the surface of Warren County. The depth map was produced by accessing the oil and gas well records from the Kentucky Geological Survey homepage (Figure 8 and 9) (www.uky.edu/KGS/home.htm, Retrieved 9/1/03). From the oil and gas well source, an Arc IMS map was accessed and Warren County was identified (Figure 10). All of the oil and gas wells in the state of Kentucky were downloaded. The oil and gas wells that pertained to Warren County were chosen and exported into GIS. A shape file of Warren County was loaded into GIS as well as Bowling Green's city boundaries. After the shape file of Warren County had been loaded into GIS a grid with cell sizes of 1.6 km by 1.6 km (one mile by one mile) was created to overlay on the Warren County shape file (Figure 11).

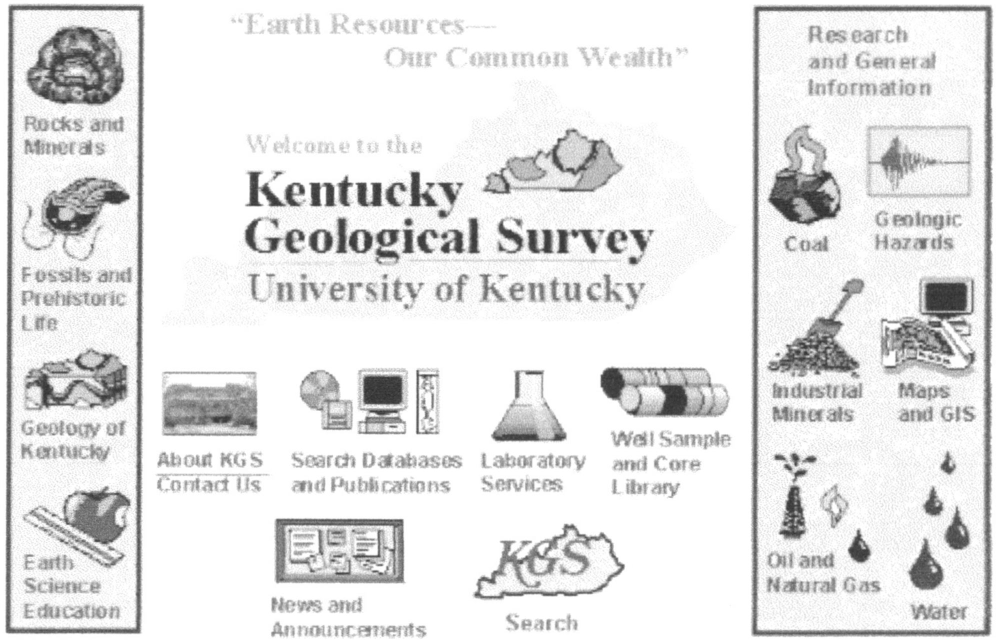
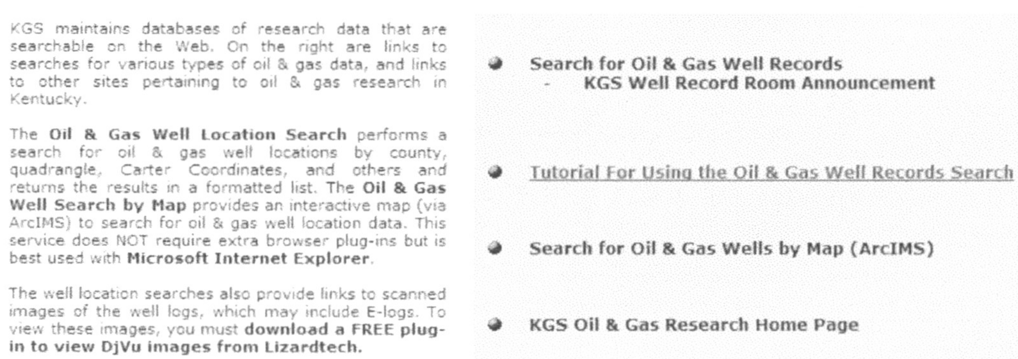


Figure 8: Kentucky Geological Survey homepage. Oil and natural gas well logs were available through this site. These well logs were used to produce the depth to the Chattanooga Shale map.
Source: Kentucky Geological Survey


KGS maintains databases of research data that are searchable on the Web. On the right are links to searches for various types of oil & gas data, and links to other sites pertaining to oil & gas research in Kentucky.

The **Oil & Gas Well Location Search** performs a search for oil & gas well locations by county, quadrangle, Carter Coordinates, and others and returns the results in a formatted list. The **Oil & Gas Well Search by Map** provides an interactive map (via ArcIMS) to search for oil & gas well location data. This service does NOT require extra browser plug-ins but is best used with **Microsoft Internet Explorer**.

The well location searches also provide links to scanned images of the well logs, which may include E-logs. To view these images, you must **download a FREE plug-in to view DjVu images from Lizardtech.**

- **Search for Oil & Gas Well Records**
  - **KGS Well Record Room Announcement**
- Tutorial For Using the Oil & Gas Well Records Search
- **Search for Oil & Gas Wells by Map (ArcIMS)**
- **KGS Oil & Gas Research Home Page**

Figure 9: Kentucky Geological Survey oil and gas well search page. Oil and gas well logs were accessed from this page in order to produce the depth to the Chattanooga Shale map.
Source: Kentucky Geological Survey

Figure 10: Warren County, Kentucky, oil and gas well search map. This map shows all the oil and natural gas wells in the County. The black points represent active oil wells, the dark gray points represent active natural gas wells. The hollow circles represent no longer active oil or natural gas wells. The shaded area is the county boundary.
Source: Kentucky Geological Survey

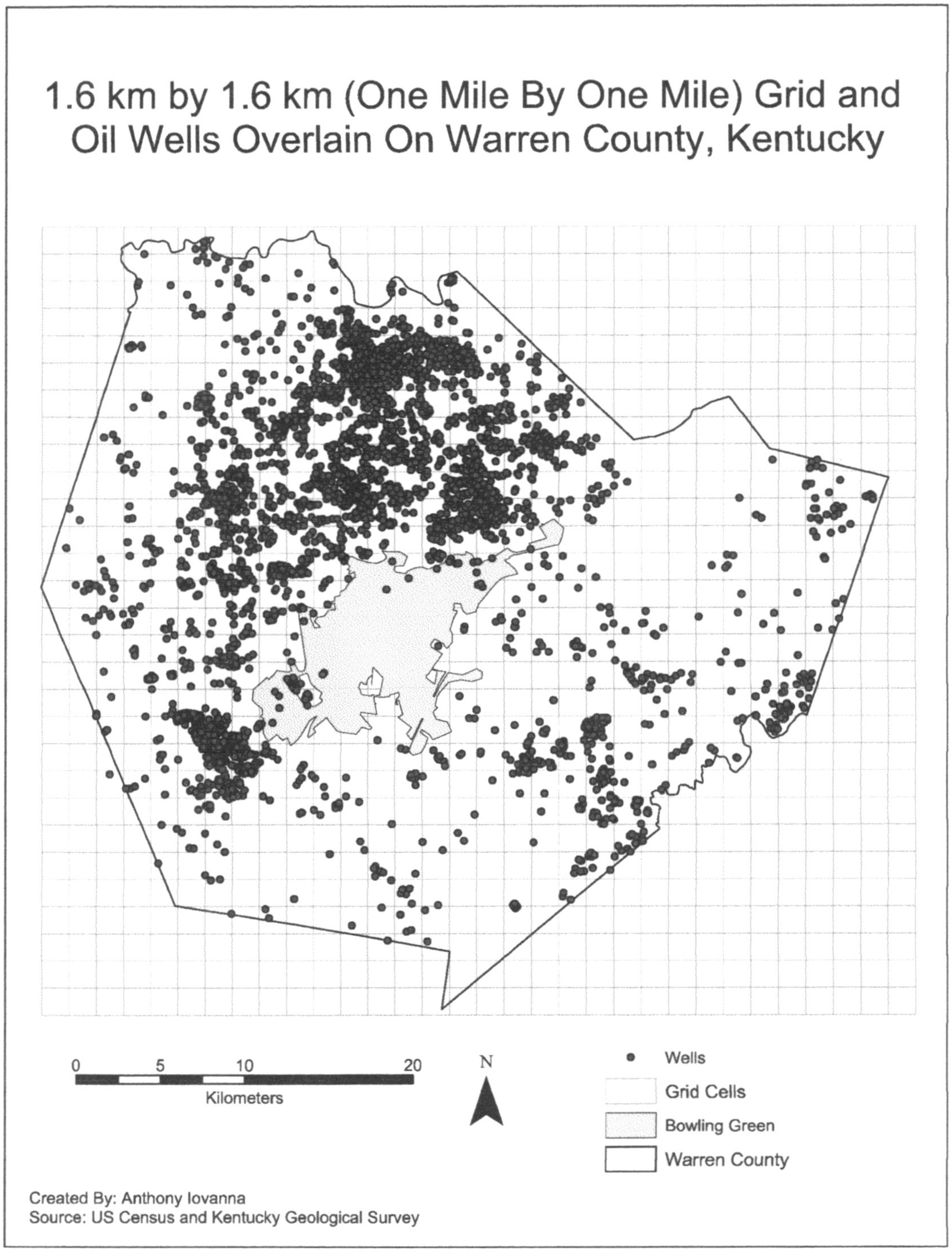


Figure 11: A 1.6 km by 1.6 km (one mile by one-mile) grid overlain on an outline of Warren County, Kentucky, included are the oil and gas wells that were retrieved from the Kentucky Geological Survey. The 2000 city boundaries of Bowling Green were included.
Source: US Census Bureau (2000) & Kentucky Geological Survey

The 1.6 km by 1.6 km (one-mile by one-mile) grid was loaded into GIS and the attribute table of the grid and the attribute table of the oil and gas well data points were joined together. This procedure assigned all the wells that fell within a given grid cell to that particular grid cell. Furthermore, because each grid cell had a definite number of wells within its borders it was possible to create a well density map. The result was a chloropleth map that shows the density of oil and gas wells across Warren County (Figure 12).

These maps were overlain with a GIS layer that showed the locations of two hundred and seventeen radon test points in Warren County. These test points were retrieved from a local radon tester, who tested homes at the request of the homeowner. The tester used a continuous flow monitor to test the homes for radon pollution. In many of the test cases the radon test was conducted in conjunction with a real estate transaction.

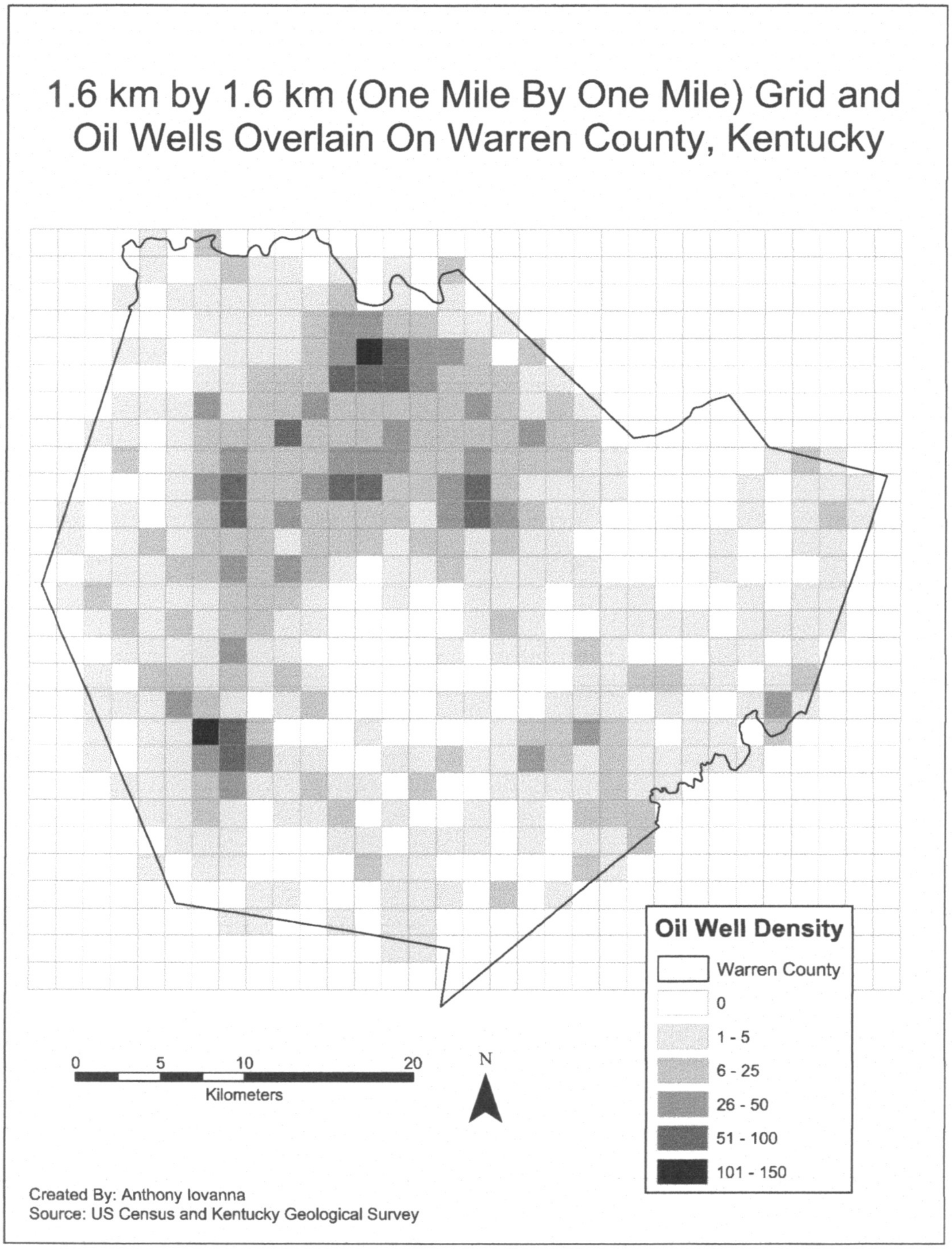


Figure 12: Oil and gas well density map. A 1.6 km by 1.6 km (one-mile by one-mile) grid with the outline of Warren County, Kentucky, shows the well density across the County.
Source: Kentucky Geological Survey

Some of the grid cells had no wells in them while some cells had a very large number. Information that was used included the KGS record number for the well, the total depth of the well, and the elevation of the well above sea level. Once all the wells had been chosen, the oil and gas well records database was accessed through the Kentucky Geological Survey (KGS) website to get the depth to the Chattanooga Shale from the surface. The drilling log for each well with the depth to different geological formations was accessed (Figure 13). Some of the well logs were not used if they were not drilled deep enough to have determined the depth of the Chattanooga Shale. Also some of the logs were illegible; as a result the depth that the Shale was encountered could not be determined. The depth that the Shale was encountered during drilling was recorded in the spreadsheet under "Shale Depth" and converted into a raster GIS image. Through this process a depth to the Chattanooga Shale map of Warren County was produced (Figure 14).

Because some grid cells had no data, a spatially interpolated depth to Shale map was created using kriging, using the depths to the Shale as the variable that was kriged. This method produced a continuous map of the surface of the Shale (Figure15).

FORMATION RECORD

From	To	Rock Type (describe rock types and other materials penetrated and record occurrences of oil, gas and water from surface to total depth)	From	To
0	14	Red Clay		
14	55	White Lime		
55	80	Grey Lime		
80	90	Jackson Sand		
90	102	Grey Lime (Sulfur Water)		
		Landed 102.7 Ft., 7" Casing		
102	140	Grey Lime		
140	200	Lt. Brown Lime		
200	290	Black Lime		
290	390	Lt. Brown Lime		
390	485	Grey Lime		
485	800	Dark Grey Lime		
800	983	Black Lime		
983	993	Green & Brown Lime		
993	1090	Black Shale		
1090	1100	Black Lime		
1100	1130	White Lime		
1130	1159	Lt. Brown Lime		
1159	1169	White Lime W/Brown Flakes		
1169	1179	White Lime		
1179	1186	Grey Lime		
1186	1196	White Lime		
1196	1208	White Lime		
		Show of oil		
1208	1215	White Lime		
1215	1230	Brown Lime		
1230	1245	Lt.Tan Lime		
		Show of Oil		
	1245	T.D.		

Figure 13: An Oil and gas well log example. This shows a page of a well log that listed what strata was drilled through. In this example, the Chattanooga or Black Shale was encountered at 303 meters (993 feet) below the surface. The well was drilled to a total of 379 meters (1245 feet) below the surface. This is an example of a good well log. The log included the Shale and was easily readable. Some of the well logs that were "bad" were written out by hand and hard to read and/or did not include the Shale in their list of strata encountered.
Source: Kentucky Geological Survey

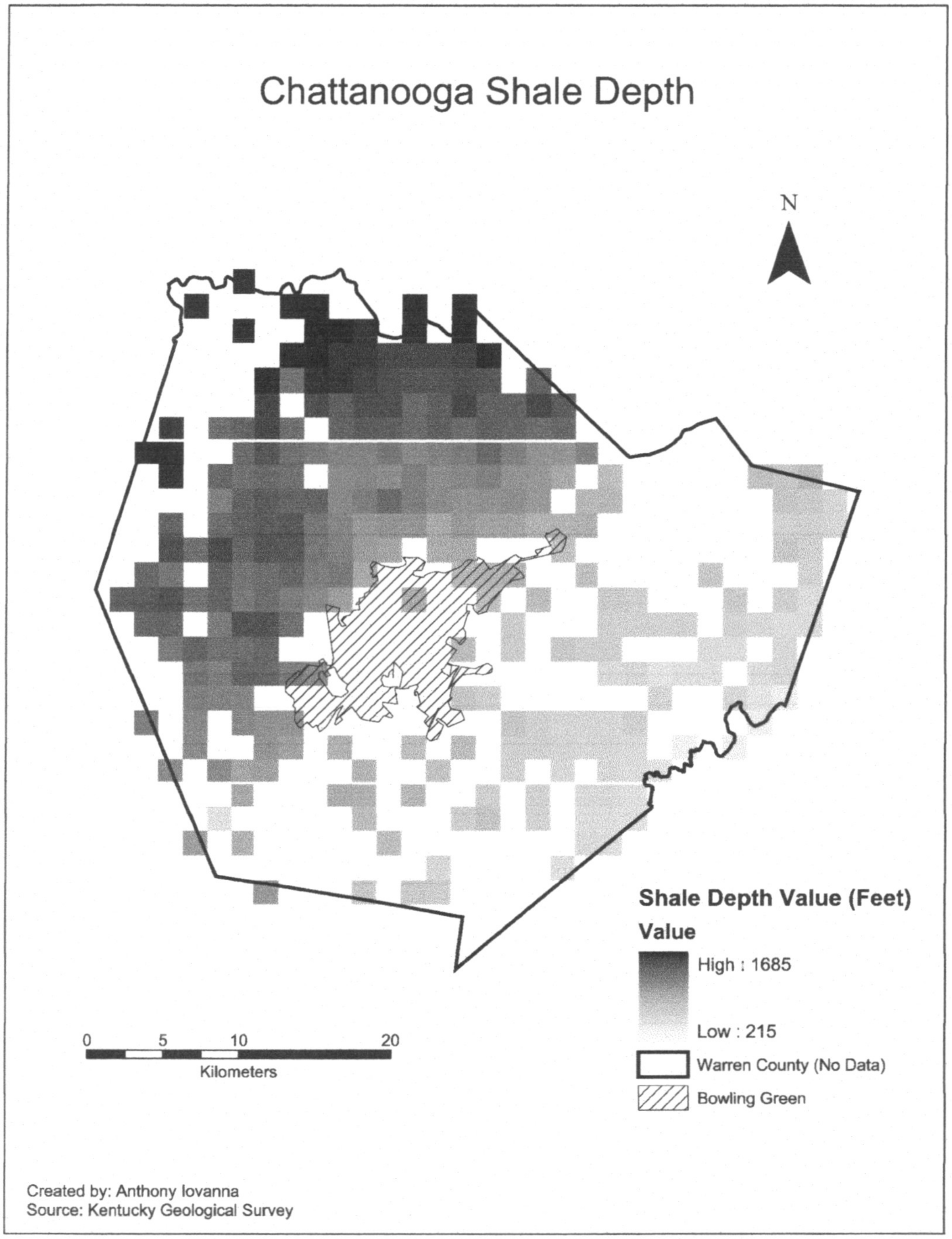


Figure 14: The depth of the Chattanooga Shale below Warren County. This map was produced using the 1.6 km by 1.6 km (one-mile by one-mile) grid. Each of the grid cells was assigned the average depth to the Shale from the wells within each of the grid cells. Each of the grid cells was assigned a color depending on the depth of the Chattanooga Shale below the surface. There were a lot of areas of "no data". These are the white areas of the map. The Shale is the closest to the surface, 215 feet, 66 meters in the southeast. The Shale slopes to the northwest and is at its deepest point, beneath the County, is 1685 feet, 514 meters below the surface, of the County.
Source: US Census Bureau (2000) & Kentucky Geological Survey

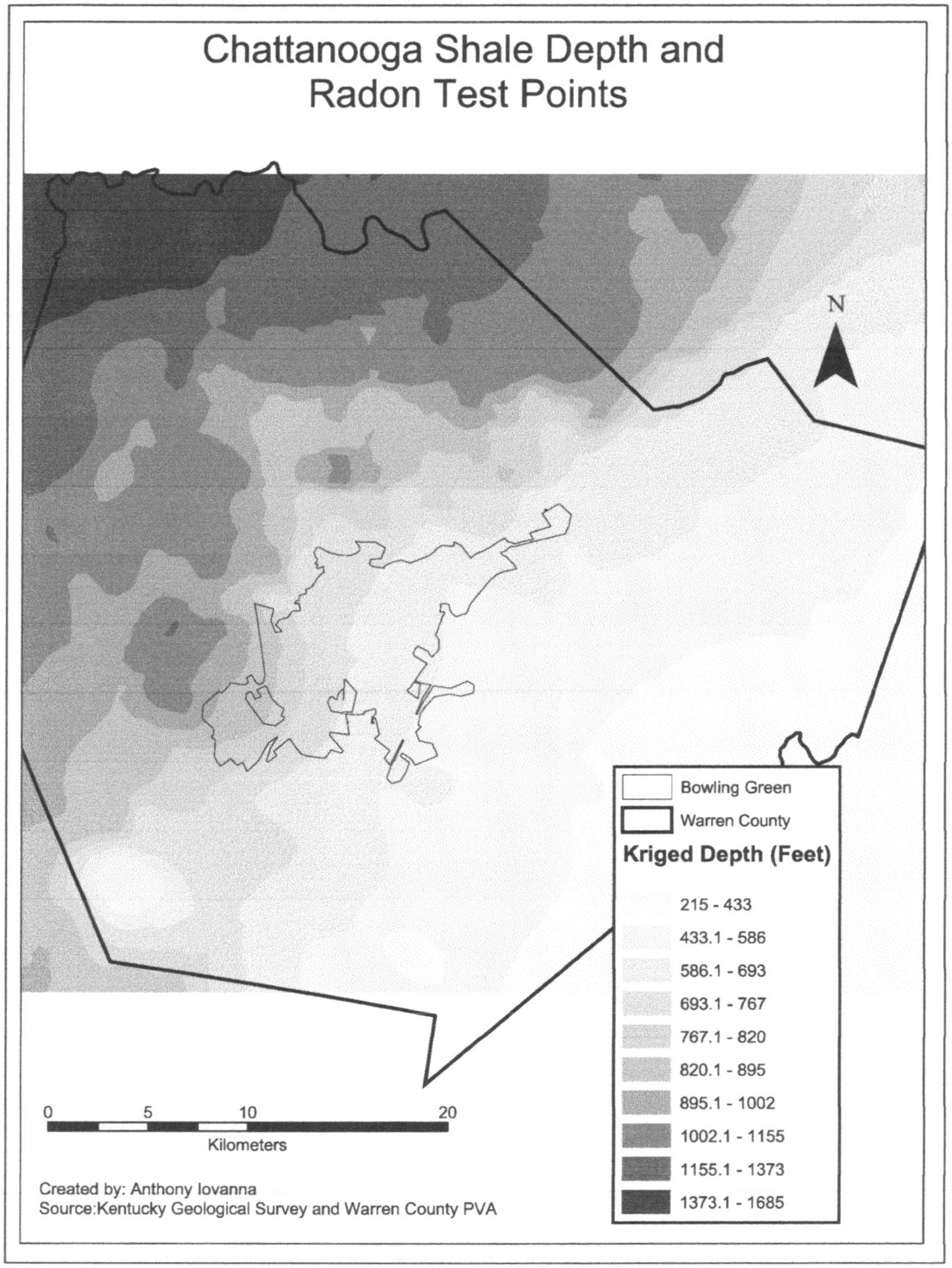


Figure 15: The kriged Chattanooga Shale depth below Warren County. Kriging filled the areas of "no data" by interpolating from the areas with data. The Shale is the closest to the surface, 66 meters (215 feet) in the Southeast. The Shale slopes to the northwest, where it is deepest, 514 meters (1685 feet) below the surface.
Source: US Census 2000 Bureau & Kentucky Geological Survey

Chapter Two

Testing and Mitigation Techniques

Radon exposure is a serious health risk; however, high levels of radon exposure are easily preventable. It is important that homes be tested to determine their radon level. Testing techniques range from very to moderately inexpensive and easy to carry out. Once testing has been done mitigation can take place, if needed. Through education, testing, and mitigation the health threat radon poses can be minimalized. Furthermore, policy changes would make education, testing and mitigation easier and more widespread.

Testing

There are two types of residential radon tests: short-term and long-term tests. According to the US EPA (1993), common types of short-term tests include charcoal canisters, liquid scintillation detectors, and continuous flow monitors. Charcoal canisters and liquid scintillation detectors contain small amounts of activated charcoal. Radon and its decay products are absorbed onto the charcoal and measured in a lab. Continuous flow monitors require power and must be operated by trained testers. This type of test continuously records the amount of radon in the home. These short-term tests remain in the home between two to ninety days depending on the testing method. Short-term tests are conducted under "closed house conditions." More specifically, the house is tested with the windows and doors shut so there is a maximum concentration of radon in the home during the testing period. Short-term tests allow the homeowner to assess the radon risk potential in order to determine if a long term-test is needed.

Short-term tests only assess a potential problem because radon levels can vary from day-to-day and season-to-season. This variation is caused by changes in air pressure and temperatures. Therefore a long-term test can accurately assess the yearly radon average for a home (US EPA, 1993). Long-term tests suggested by the US EPA (1993) include alpha track detectors and electret ion chambers. Alpha track detectors contain a sheet of plastic that is exposed between one and three months. The alpha particles emitted by radon etch the plastic as they strike it. The radon value is then calculated by examining the number of etches on the plastic. Electret ion detectors contain an electrostatically charged Teflon disk. Ions produced from the breakdown of radon strike the disk and reduce the surface voltage of the disk, which is then analyzed to determine the radon value of the home. Long-term tests last at least ninety-one days and are conducted under "normal living conditions."

Radon Mitigation Methods

The US EPA (1993) lists two radon reduction methods: preventing the entry of radon into the home, and removing radon once it has entered the home. According to the US EPA, sub-slab suction (Figure 16) is the most popular method of removing radon from homes. This method uses a fan to remove radon from beneath the foundation and vent it outside of the house. Pipes are drilled through the concrete floor. A fan in the basement vents radon that accumulates beneath the slab. These pipes discharge the radon away from the home (Brenner, 1989; Brookins, 1990; Cook and Egan, 1987). However, Brookins (1990) states sub-slab venting alone might not be adequate to lower radon levels if the home has hollow block walls. In these cases, block wall ventilation must be used. Brenner (1989) states that the effectiveness this method depends on the permeability of the soil beneath the house. Furthermore, the number of pipes needed in this method is dictated by the size and shape of the home. Overall this method has proven to be effective in lowering radon concentrations in homes (Brenner, 1989; Brookins, 1990; Cook and Egan, 1987). Brookins (1990) lists a ninety-five percent success rate in lowering radon levels.

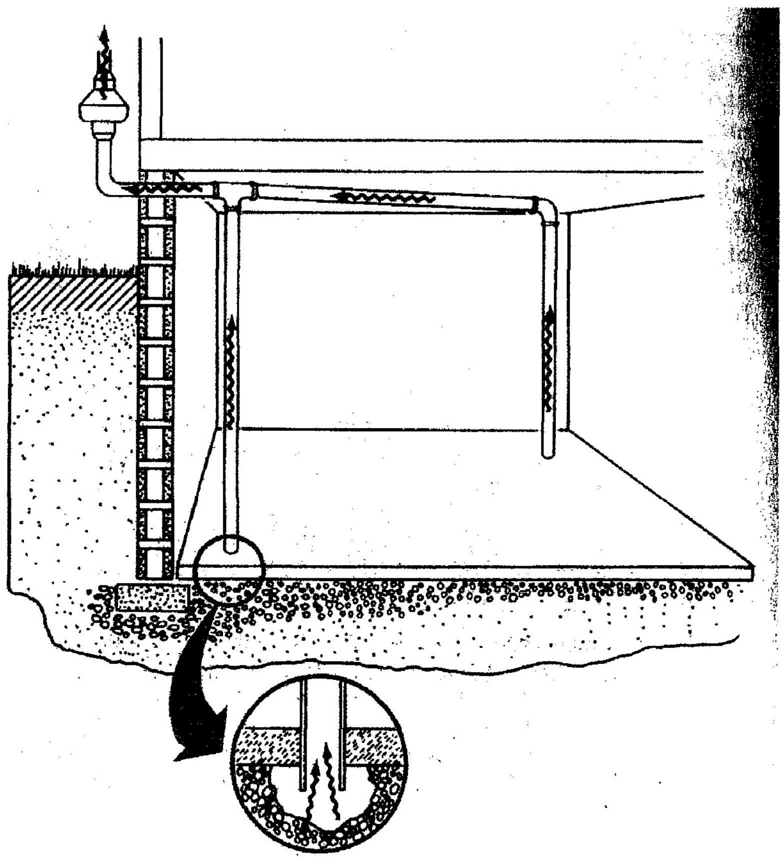


Figure 16: Pipes are inserted into the ground and radon is pulled through those pipes by a fan and the radon is expelled in outdoor air (Taken from Brenner, 1989).

Drain-tile ventilation (Figure 17) is an effective method for preventing radon from entering homes. Drain-tiles are used to drain water away from homes. If drain tiles surround the house they can be used, with a fan, to vent radon into the outdoor atmosphere (Brenner, 1989; Brookins, 1990; Cook and Egan, 1987). According to Brenner (1989), Brookins (1990), Cook and Egan (1987) this method is easy to implement and very effective, if the house has drain-tiles encircling the entire house.

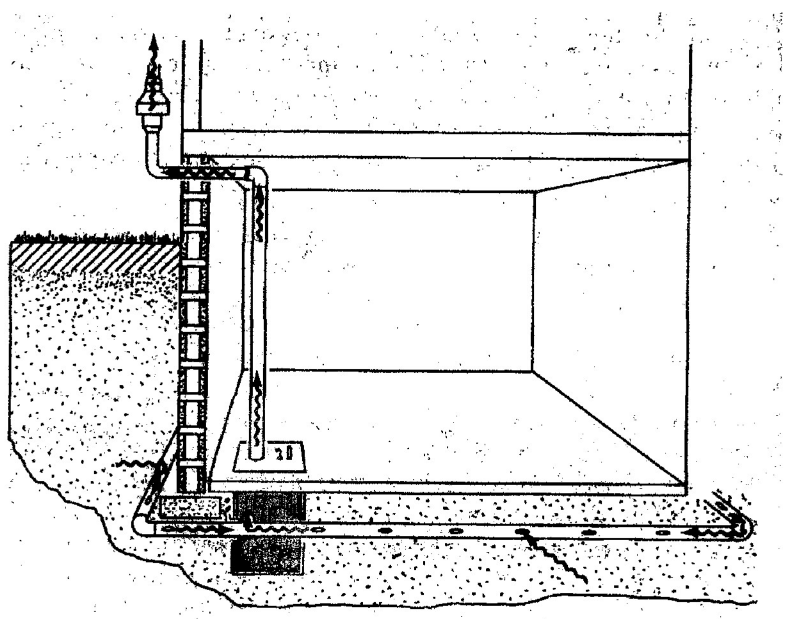


Figure 17: Radon and water enter into a sealed sump and an outside fan pulls the radon into the outdoor air (Taken from Brenner, 1989).

A third method is block wall ventilation (Figure 18 and 19). This method uses a fan to pull air out of the hollow cavities of block walls. Hollow block walls can serve as conduits for radon to enter the home. In order to vent radon from the block walls pipes are placed into the walls and then an outside fan pulls the radon outside (Brenner, 1989; Brookins, 1990; Cook and Egan, 1987). There are two methods of venting block walls, one is the pipe-in-wall technique and the other is the baseboard technique (Brenner, 1989). These techniques are not as effective as the others. Cracks in the walls can cause an inadequate amount of suction to be generated by the fan outside the house, and as a result one does not receive the most effective radon removal available (Brenner, 1989; Brookins, 1990; Cook and Egan, 1987).

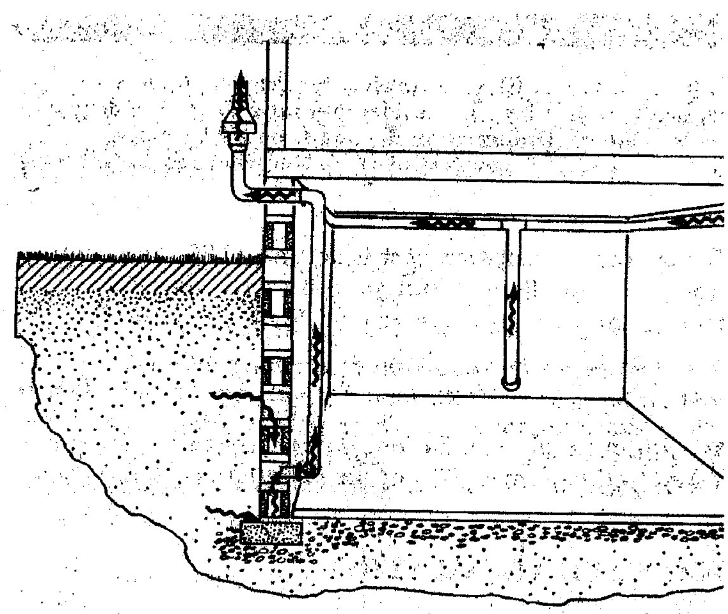


Figure 18: Pipes are inserted into the block wall. These pipes then pull the radon out, by means of a fan, and vent the radon into the outside air (Taken from Brenner, 1989).

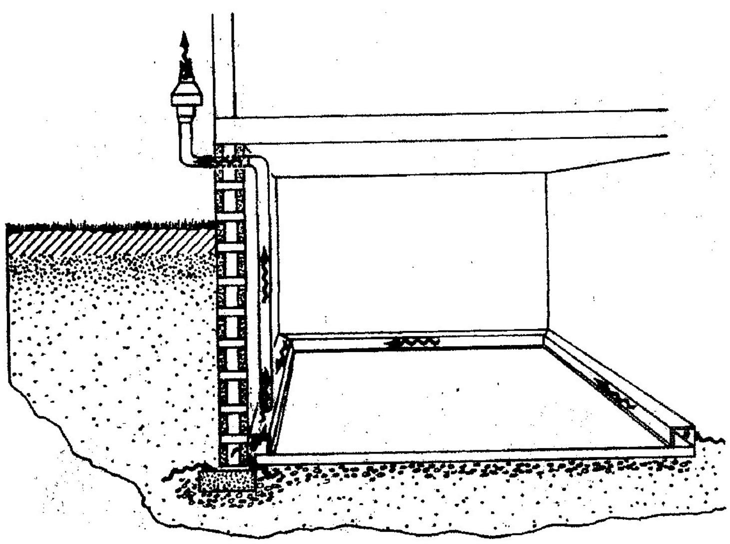


Figure 19: A baseboard duct is used. Holes are cut into the block walls, along the floor, and a baseboard duct is sealed to the wall. The radon is pulled through a pipe and vented into the outside air by a fan (Taken from Brenner, 1989).

These radon reduction methods can cost between 500 and 2,500 dollars and the average price is around 1,200 dollars (US EPA, 1993). Some other methods of providing a barrier to keep radon from entering a home include the following: tightly sealing all air ways to the subsurface below a home, placing an impervious membrane beneath the home, and using epoxy paint to seal the interior walls (Crowther, 1989).

There are radon reduction methods, in addition to the methods listed above, that have been built into newer homes. One of these methods is to pour the foundation of the home as one unit so that there are no joints between the floor slabs and the wall slabs. This method prevents radon from entering the home through joints in the foundation. Another method is placing a plastic barrier under the foundation slab. This barrier does not allow radon to enter the home from under the cement slab. Furthermore using re-bar to create a skeleton for the cement foundation helps the foundation to resist cracking and therefore limit the number of passages radon can use to enter the home (Crowther, 1989; Intergrated Environmental Management, 1999).

Policy Responses

Although methods for reducing radon in newly built homes are available, the public does not appreciate the threat of radon. The US EPA website, retrieved 5/10/04, stated that only 5.8 percent of 1,124,000 single family homes built in 2001 incorporated radon reduction features; and more troubling, only 11.7 percent of 255,000 single family homes built in areas of high radon potential during 2001 had radon reducing features.

Within the state of Kentucky there are no mandatory building codes that require new homes to have radon mitigation built into their designs. When the individuals are properly informed, they can take action against potentially high radon levels in their homes. Although radon preventive measures are not required, many new homeowners are requesting that radon mitigation be built into their homes.

Radon contamination or the possibility of contamination must be acknowledged by the homebuilder, real estate agents, and the home seller. The homebuilder is liable for radon if a structural defect has led to high radon levels. These defects can include cracks in the foundation and inadequate sealing around pipes. Furthermore, if there were no structural defects but the builder was aware of a potential radon problem, the builder can be found liable for negligence in not mitigating the radon problem (Brenner, 1989).

Real estate agents can be held responsible if they knowingly do not disclose to the potential buyer the presence of a radon problem. The agent may still be liable even if he/she did not know about the high radon levels. According to Brenner (1989) this ruling is due to the Code of Ethics of the National Association of Realtors. This code states that a realtor is responsible for uncovering any adverse factors that a competent investigation might uncover (Brenner 1989).

Brenner (1989) states, if the seller knows there is a high radon level, he/she must inform the buyer, otherwise the seller would be committing fraud and subject to criminal prosecution. There are several ways that a radon problem can be dealt with. One of these ways is to have the seller reduce the price of the home by the average cost of mitigation. Another approach is to set up an escrow account that will pay for any mitigation expenses or mitigation can be performed prior to the sale.

In existing homes, it is up to the consumer to be educated about radon. If a potential buyer requests the seller to have a radon test performed, the seller must have the test performed just as for termites. If the seller refuses to have the radon test carried out, the potential buyer can walk away from the deal or can try to negotiate a purchase contract that would state, if radon was found above the US EPA action level of 4 pCi/l, the seller of the home would pay for the mitigation costs.

However, if the seller of a home does agree to get the house tested, the results of the test must be disclosed to any other potential buyers. If the results of the test are not disclosed, both the seller of the home and the real estate agent involved can be charged with fraud. Although a home may have a radon level above the US EPA's action level, the house can be sold as long as radon test level is disclosed to the buyer. In most cases, the price of mitigation will be negotiated into a purchase contract with the seller of the house.

When building or buying a home, it is the duty of the buyer to be educated about radon, as well as other natural hazards – such as flooding or termites. Furthermore, radon is not seen as a threat by people throughout the United State and individuals must be educated about radon. They must understand how it is formed, where it comes from, how it enters the home, what it can do to one's health, and how to mitigate the problem. By being educated on these aspects of radon, individuals can assess their own risk and determine if they should have a radon test performed on their home.

Chapter Three

Summary of Current Study

This study compared depth to a potential radon source and the socio-economic factors of the homes tested for radon. By comparing these factors it was possible to determine if proximity above a potential radon source or home characteristics lead to high radon measurements in homes.

The major data set was residential radon measurements taken in two hundred and seventeen homes. A local radon tester conducted these tests, usually as part of a real estate transaction. Oil and gas wells for Warren County, Kentucky, were downloaded, along with their well logs, data from which allowed the depth to the top surface of the Chattanooga Shale map to be completed. The radon test point measurements were compared to the depth of the Chattanooga Shale map. This comparison was done to determine if the high radon values were located where the Chattanooga Shale was closest to the surface.

Warren County Property Value Administration (PVA) and US Census Bureau data were also collected. The Warren County PVA data included GIS shapefiles of all the land parcels within Warren County (Figure 20). For each of the parcels, data in the attribute table included the address, the year the home was built, the square area of the home, and whether or not the home had a basement. These characteristics were used to determine if they correlated to high levels of residential radon. The 2000 US Census Bureau data was used to determine the economic status of the households that were being tested for radon.

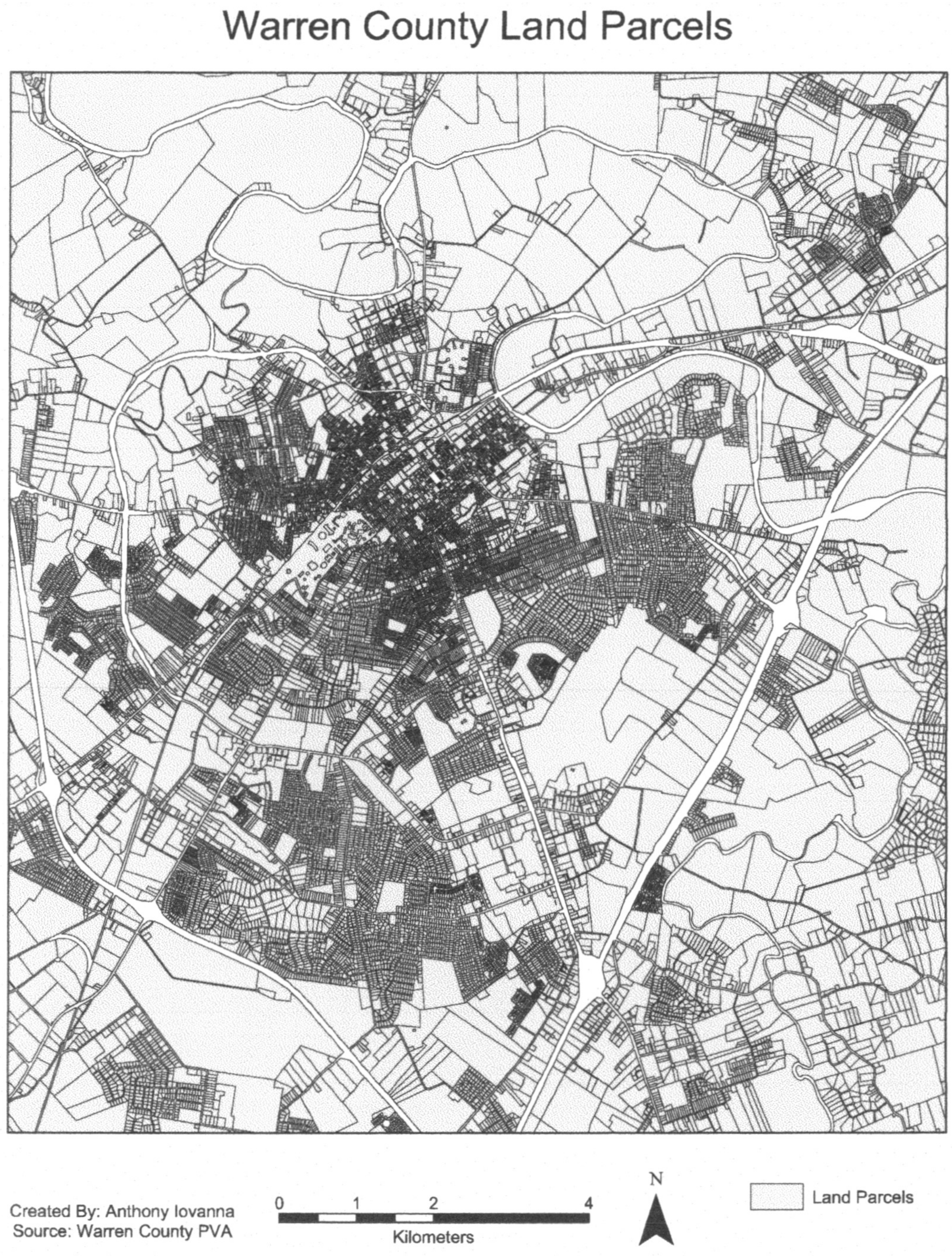


Figure 20: Sample of land parcels in Warren County. Each parcel had attributes, such as: home age, home size, presence of a basement, type of heating and cooling unit, the addresses of the parcels, etc. The black areas of very high density development with very small parcel sizes and correspond to the downtown areas of Bowling Green. From the Warren County Property Value Administration.

For this study, it was hypothesized that homes built after 1977 would have a higher probability of having radon values above 4 pCi/l than older homes. The premise was that homes built after 1977 are better sealed than homes built before 1977 and as a result would not allow radon to leave the home once it had entered through crawl spaces or the basement. It was further hypothesized that homes with basements would have higher radon values than homes without basements because there is more surface area of the foundation below the surface, and as a result there are more possible avenues for radon to enter a home that has a basement. It was hypothesized that homes with an area above 139 square meters (1500 square feet) would have higher radon values than homes below 139 square meters (1500 square feet) in area. Homes above 139 square meters (1500 square feet) in area acted as a proxy for expensive homes, and it was hypothesized that more expensive homes would be more energy efficient, better sealed, and as a result have higher radon levels. Finally, it was hypothesized that the vertical proximity of the Chattanooga Shale to homes would not have an effect on the location of high radon levels.

Statistics were performed to determine if there was a relationship between certain housing characteristics and the presence of a high radon level. Statistics were used to determine if there was a correlation between the test point's proximity to the top surface of the Chattanooga Shale and the test points possessing high radon values. The two-sample difference of proportions tests were run on homes built before 1977 and homes built after 1977, homes with basements and homes without basements, and homes below 139 square meters (1500 square feet) and homes above 139 square meters (1500 square feet). The two-sample difference of means test was run on the test point's proximity to the Chattanooga Shale. This test was used to determine if a relationship existed between the proximity of test points to the Chattanooga Shale and high radon values.

Homes built before 1977 were found to have a higher probability of measuring above 4 pCi/l. This result may be due to older homes having been built deliberately over cracks and fissures in the ground (Crawford, 2001). Homes with basements were found to have a greater probability of having a radon level above 4 pCi/l. Basement homes provide a greater amount of surface area for radon to potentially enter a home (Cook and Egan, 1989). Homes above 139 square meters (1500 square feet) were found not to have a higher probability of having a radon level above 4 pCi/l than homes below 139 square meters (1500 square feet). This result may be because there were not enough test points that were below 139 square meters (1500 square feet). Therefore an accurate representation of radon measurements in homes below 139 square meters (1500 square feet) is not known. The depth of the Chattanooga Shale did not have a significant impact on the radon levels that were recorded in Warren County homes. The intervening limestone units that lie between the potential radon source and the homes can potentially effect the radon measurements in the homes.

These results show that the depth of the Chattanooga Shale below the surface of Warren County does not play a significant role in causing high radon concentrations. It was determined that there is a significant relationship between the homes built before 1977 and high radon concentrations. Therefore future testing should focus on homes that were built before 1977. A significant relationship, although a statistically weak one, exists between basement homes and a high concentration of radon. There was no significant relationship between house size and high radon concentration. From these results it was determined that there must be other factors such as the karst, which underlies Warren County, causing high concentrations of radon to form in homes.

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Appendix One

Evaluating Uranium Depth and Socio-economic Statistics for Residential Radon Vulnerability in Warren County, Kentucky.

Anthony Iovanna, John All, and Andrew Wulff

To be submitted to: Southeastern Geographer: Journal of the Southeastern Division, Association of American Geographers

Warren County, Kentucky, has high levels of residential radon, which is a radioactive daughter product of uranium. According to the US EPA, radon exposure causes approximately 22,000 lung cancer deaths in the United States per year. The City of Bowling Green is underlain by karst, as easily soluble limestone subsurface, which allows radon gas to travel easily through cracks and fissures. The karst is underlain by the Devonian Chattanooga Shale, a low-grade uranium ore and a potential source of radon gas. A digital map of the Chattanooga Shale was created using Arc GIS. A 1.6 km by 1.6 km (one-mile by one-mile) grid for Warren County was generated and oil wells depth data within each grid cell were averaged to render the Chattanooga Shale in a digital format. A socio-economic GIS of Warren County was created using US Census Bureau and Property Value Administration data. The Chattanooga Shale and the socio-economic layers were correlated to test points that have high residential radon measurements to determine whether proximity to the shale layer or home type is the better predictor for radon risk. Once risks have been determined, management decision-making is simplified and resources can be targeted towards high need areas. Due to this lack of a geologic pattern it is recommended that radon mitigation systems be included in all new home construction and design.

Key Words: Radon, Karst, Environmental Policy, Public Health, GIS

Introduction

Up to 22,000 people die each year from lung cancer resulting from exposure to radon gas, thus making radon the second leading cause of lung cancer -- cigarette smoking being the first order (Ganas, et al.1989; Nero, 1998). The US Environmental Protection Agency (US EPA, 2001) has indicated that more people die each year from radon induced lung cancer than from drunk driving accidents.

This research examines the relationship between bedrock geology, home characteristics, and the levels of radon gas found in homes. Efficient identification of residences in need of mitigation throughout areas with potentially high concentrations of radon can be achieved by identifying risk factors. Spatial analysis of residential radon measurements will facilitate the identification of structures that potentially need to be mitigated in order to bring their indoor radon levels to an acceptable level. Possible house characteristics that may affect measured radon levels are the presence of a basement, age of the home, size of the home, and proximity to the source of radon. The purpose of this study is to address the relationship between dangerously high levels of radon gas in Bowling Green, Kentucky, and the underlying geology. The hypothesis of this study is that dangerously high indoor levels of radon pollution in Bowling Green are not influenced by their proximity to a potential uranium bearing strata and are instead a result of home characteristics.

Background

Radon is a colorless, odorless, noble gas that occurs naturally in the environment from the spontaneous breakdown of uranium 238 as it decays to lead 206 (Environmental Chemistry, 2004) and is present in many rock types worldwide. Many soils and underlying bedrock contain uranium, and radon contamination is a potential problem throughout much of the world (JAMA, 1987; Nero, 1988a).

The half-life of radon is only 3.825 days (Environmental Chemistry, 2004). Half-life is the amount of time it takes for one half-life of the atoms of an unstable element to decay radioactively into another element. Radon is not very buoyant in a static environment because it is one of the heaviest noble gases. Radon has a density of 9.73 g/l, much higher than nitrogen at 1.2506 g/l or oxygen at 1.429 g/l (Environmental

Chemistry, 2004); thus radon is much denser than the surrounding atmosphere. In order for radon to reach the surface it must be acted upon by outside factors to rise up through the ground and into homes. Teichman (1988) states that entry rates for radon rely upon the amount of radium, another uranium daughter, in the soil, the permeability of the soil, as well as characteristics of the dwelling.

Karst is a landscape that is formed from the dissolution of carbonate rocks, such as limestone or dolomite. Karst is characterized by caves, sinkholes, springs, disappearing streams, and the lack of numerous surface streams (Veni, et al., 2001). According to Veni et al., roughly twenty-five percent of the world is karst and approximately twenty percent of the United States is karst, with significant formations occurring in at least twenty states. A myriad of problems have been encountered that are specifically related to the karst landscape. Some of these problems include sinkhole collapse, sinkhole flooding, and the vulnerability of having an easily pollutable ground water system (Crawford 2001).

Karst is a unique situation for radon transport because karst fracturing facilitates the percolation of radon from the subsurface. According to Medici (1993), radon concentrations in caves are elevated ten to one hundred times higher than in the homes above the caves. The caves are a major source and transportation conduit for radon. Radon is able to travel significant distances fairly quickly through fractures and caves in karst. Pressure differences can cause air to flow from the karst into buildings, resulting in an increase in the indoor radon concentration (Brookins, 1990; Crowther, 1989).

Study Area

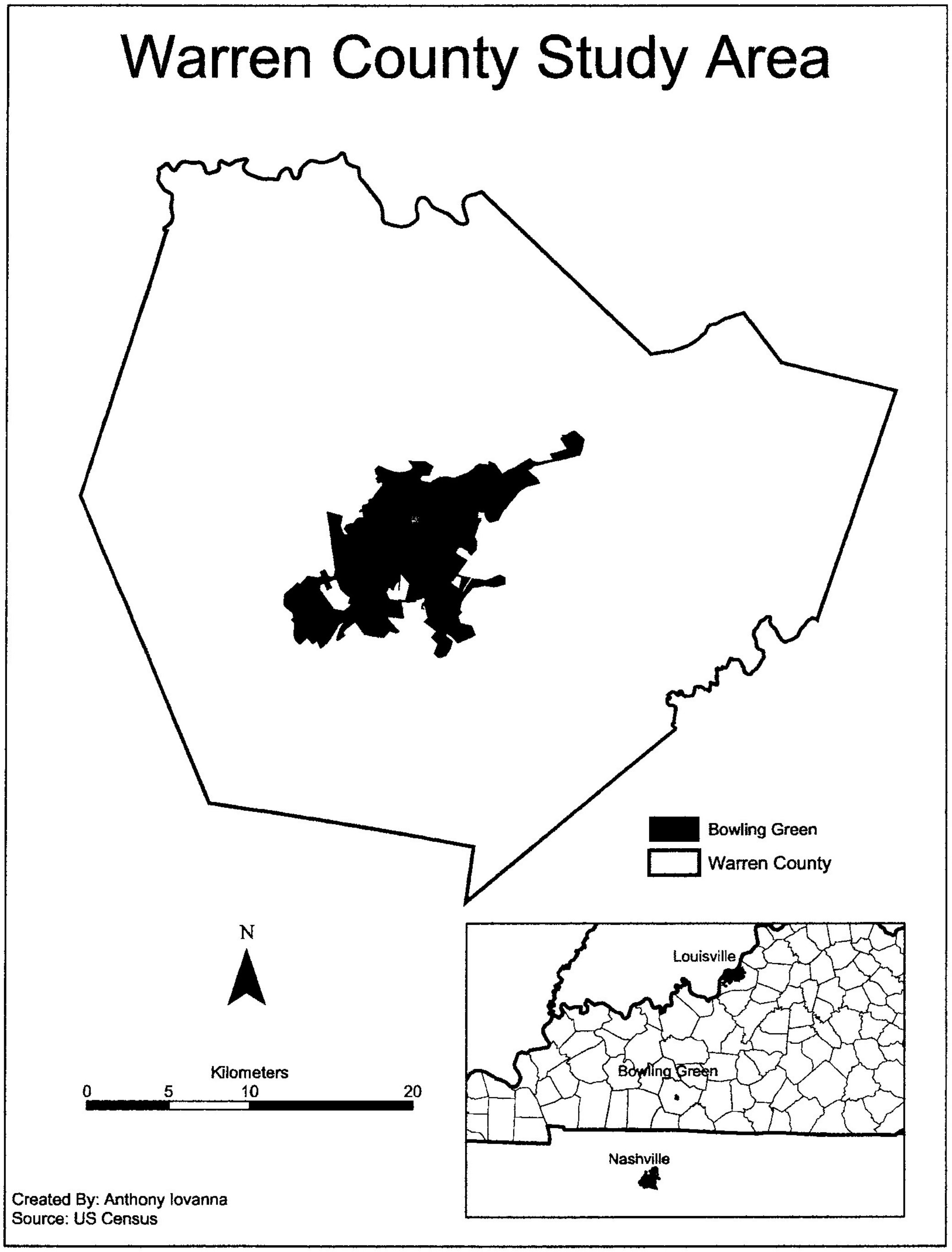

Figure 1: Warren County, Kentucky, and City of Bowling Green Study Area. Bowling Green is the dark area in the middle of the County. Produced from US Census Bureau (2000) data.
Source: US Census Bureau (2000)

This study will examine Warren County, Kentucky and focus upon the city of Bowling Green (Figure 1). The city of Bowling Green is located in south-central Kentucky, approximately 105 km (65 miles) north of Nashville, Tennessee, and approximately 177 km (110 miles) southwest of Louisville, Kentucky. Bowling Green has nearly 50,000 inhabitants within the city limits and over 90,000 inhabitants in the Warren County area (US Bureau of Census 2000).

Bowling Green lies in a geological region that is characterized as one of the "classic" karst regions because it has a complete group of karst features (Crawford, 2001; Jillson, 1928). There is a layer of shale underlying the karst, called the Chattanooga Shale. The Shale is between 61 to 488 meters (200 to 1600 feet) below the surface of Warren County. This Shale is a possible source of uranium from which the radon gas is originating (Deming, 2000; Montgomery, 1997; USGS, 1997). The uranium content varies across the layer of shale and might vary in areas smaller than a county (Swanson and Landis, 1962).

According to the Environmental Protection Agency, the level of 4pCi/l is the recommended acceptable level for indoor radon (US EPA, 1992). Radon is measured in picocuries (pCi), which is the amount of radioactivity present. In 1987, sixty percent of homes in Warren County that were tested for radon gas had levels that were above 4pCi/l (US EPA, 1987). The US EPA states that if one thousand people who never smoked were exposed to four pCi/l of radon over their entire lifetime, about two of them would get lung cancer. However, the number of potential lung cancer cases increases if there is a higher level than four pCi/l and if those exposed were smokers.

Past work in Bowling Green indicated that homes that did not have a basement had a mean of 4.73pCi/l, and in houses with basements the mean was 22.92pCi/l (Table 1) (Webster, 1990).

	Mean	Median	Range
Non-basement	**4.73 pCi/l**	**2.63 pCi/l**	**0.14 to 25.63 pCi/l**
Basement	**22.92 pCi/l**	**12.52 pCi/l**	**2.47 to 123.38 pCi/l**

Table 1: Radon values from homes in Bowling Green, Kentucky. Derived from Webster (1990).

Methodology

Nero (1988b) states that the most direct way to find dwellings with high radon levels is to conduct broad-scale systematic surveys that measure levels in a sampling of dwellings over a large region. Although identification of high-level areas has not resulted from the systematic approach, local monitoring that is done for a variety of reasons has allowed for a number of high-level areas to be identified. Local radon monitoring provides a better resolution as to which areas have high levels of radon and which areas do not. The two-hundred and seventeen test points that were compiled for this study were obtained from a local radon tester who conducted radon testing within the Warren County area in association with home sales. A second method Nero relates is in the case of Pennsylvania's Reading Prong, where the basic geological characteristics of the geological formation had been used as an indicator of the potential for areas to have high levels of radon. These methods will inform the current study in its examination of potential uranium sources.

In 1997, The University of Toledo conducted a study on indoor radon pollution levels that determined high radon levels were associated with the Wisconsinian and Illinoian tills which contained material from the Devonian bedrock (Kroll, 1998). This research determined the Devonian rock is a source of uranium. There is a Devonian layer, Chattanooga Shale, in the Warren County study area. Past research has determined that this strata contains radon and has contributed to high radon levels (Deming,2000; Landis and Swanson, 1962; Montgomery, 1997; Nininger, 1956; and the USGS, 1997)

This research hypothesizes that dangerously high levels of indoor radon pollution in the area of Bowling Green, Kentucky, do not follow the expected geological pattern that is said to govern the location of data points possessing high radon levels. Instead, the karst is expected to disrupt the pattern and individual levels to differ based upon home characteristics.

Geographic Information Systems (GIS) is a computer system for capturing, storing, querying, analyzing, and displaying geographically referenced data (Chang, 2004). GIS was used for the collected data points to be superimposed over the geological data, such as bedrock, mapped fractures, oil wells and caves. GIS was also used for kriging, a spatial interpolation method, to fill in any areas where data may be lacking (Demirel et al., 2000; Lloyd and Atkinson, 2002). Environmental Systems Research Institute (ESRI) Arc Info 8.X was the primary analysis tool used in this research.

Data

Research data included residential radon measurements, residential characteristics, oil well drilling logs and census block group economic data. In most states, only licensed contractors can only carry out radon testing and mitigation. Residential radon measurements were obtained from a licensed local mitigation contractor who used a continuous flow monitor to collect the test point readings. The testing device was a continuous flow monitor with a movement sensor. The movement sensor allows the licensed tester to know if the continuous flow monitor was moved during the testing time period. Tests were performed as part of a real estate transaction and the cost of the test, greater than one hundred dollars, generally limited the data points to more affluent homes.

Residential characteristics were obtained from the Warren County Property Value Administration (PVA) as Arc GIS shapefiles. Information about the parcels, such as the age of the home, whether there was a basement or not, what type of heating and cooling system was present, the square area of the home, the address of the parcel, etc, were located in the parcel files attribute table. The address of the parcel allowed for the radon test points to be joined to the parcel attribute table.

In total, 3,897 Warren County oil well drilling logs were available from the Kentucky Geological Survey (KGS 2003). These well logs have the various rock strata encountered during drilling including the depth that the Chattanooga Shale was encountered. The logs also recorded the elevation of the well being drilled as well as its geographic coordinates.

Census block group economic data were obtained from the US Census Bureau (2000). This data consists of seventy-seven different block groups in Warren County and lists the number of households and the annual income levels of the households present in each block group.

Determining the Depth of the Chattanooga Shale

Chattanooga Shale is believed to be the source of low-grade uranium that releases radon gas (Deming, 2000; Montgomery, 1997; USGS, 1997). The Chattanooga Shale, in the southeastern United States, contains uranium. According to the United States Geological Survey (USGS, 1997) the Chattanooga Shale near Nashville, Tennessee contains between 0.025 and 0.035 percent uranium (Swanson and Landis, 1962).

In order to determine the depth of the Chattanooga Shale within Warren County, oil and gas well records were downloaded from the Kentucky Geological Survey (KGS) website (KGS, 2003). The oil and gas well records were utilized by searching for the wells that had been chosen from the 1.6 km by 1.6 km (one mile by one-mile) grid overlain on the County (Figure 2). This method produced the well logs for every well record number that was entered into the search. These well logs were then used to determine the depth of the Chattanooga Shale (Demirel et al., 2000) (Figure 3). Flawed well logs were discarded. Approximately 3,897 well logs were used in this study.

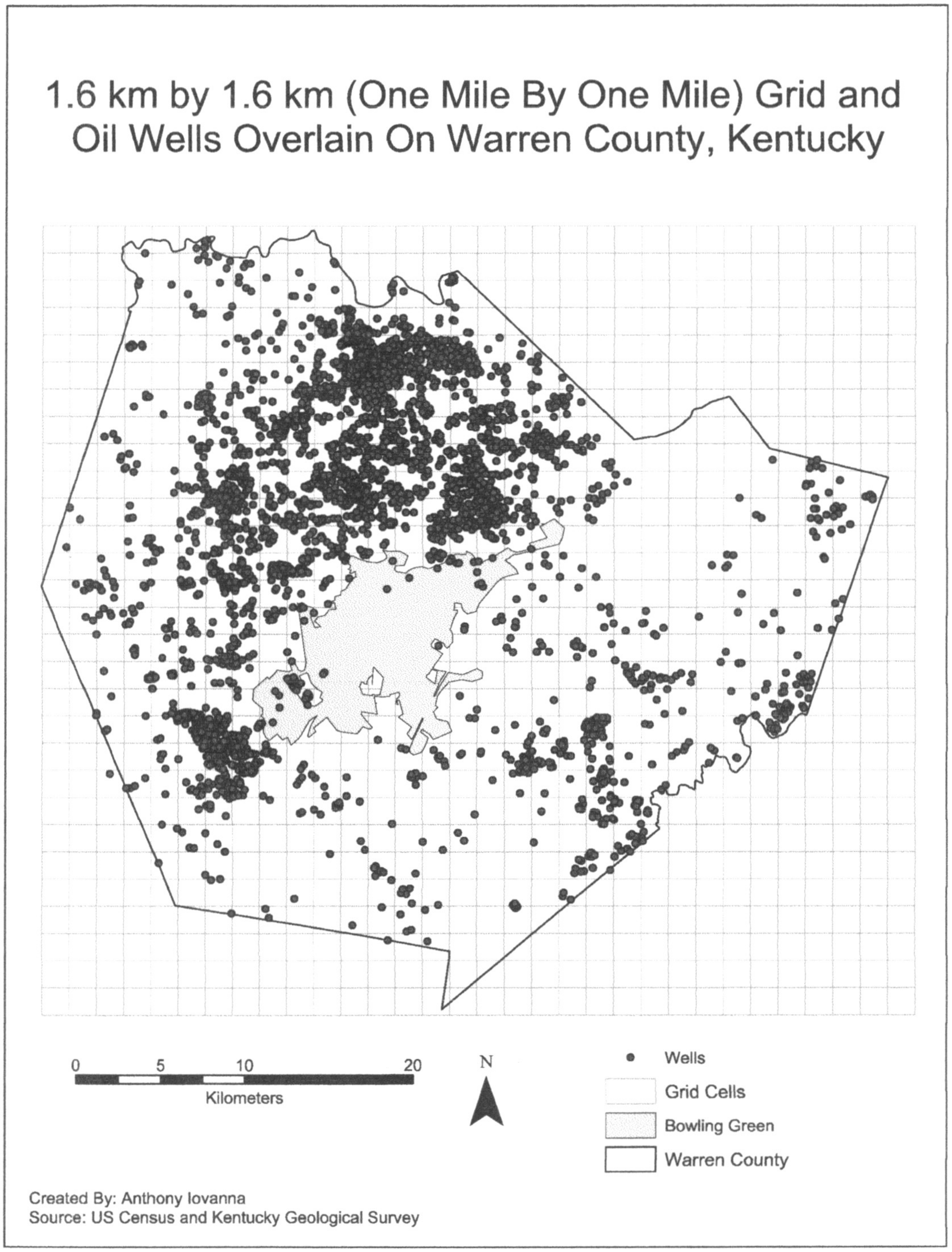

Figure 2: A 1.6 km by 1.6 km (one-mile by one-mile) grid overlain on an outline of Warren County, Kentucky. Included are oil and gas wells from the Kentucky Geological Survey. The 2000 city boundaries of Bowling Green were used and shaded in grey. This data was obtained from the Kentucky Geological Survey and the US Census Bureau (2000).

All the depths within a grid cell were averaged to result in the final depth value (Figure 3). Portions of Warren County did not have any oil wells in them and kriging, a spatial interpolation method, was used to generate values for the empty cells (Figure 4).

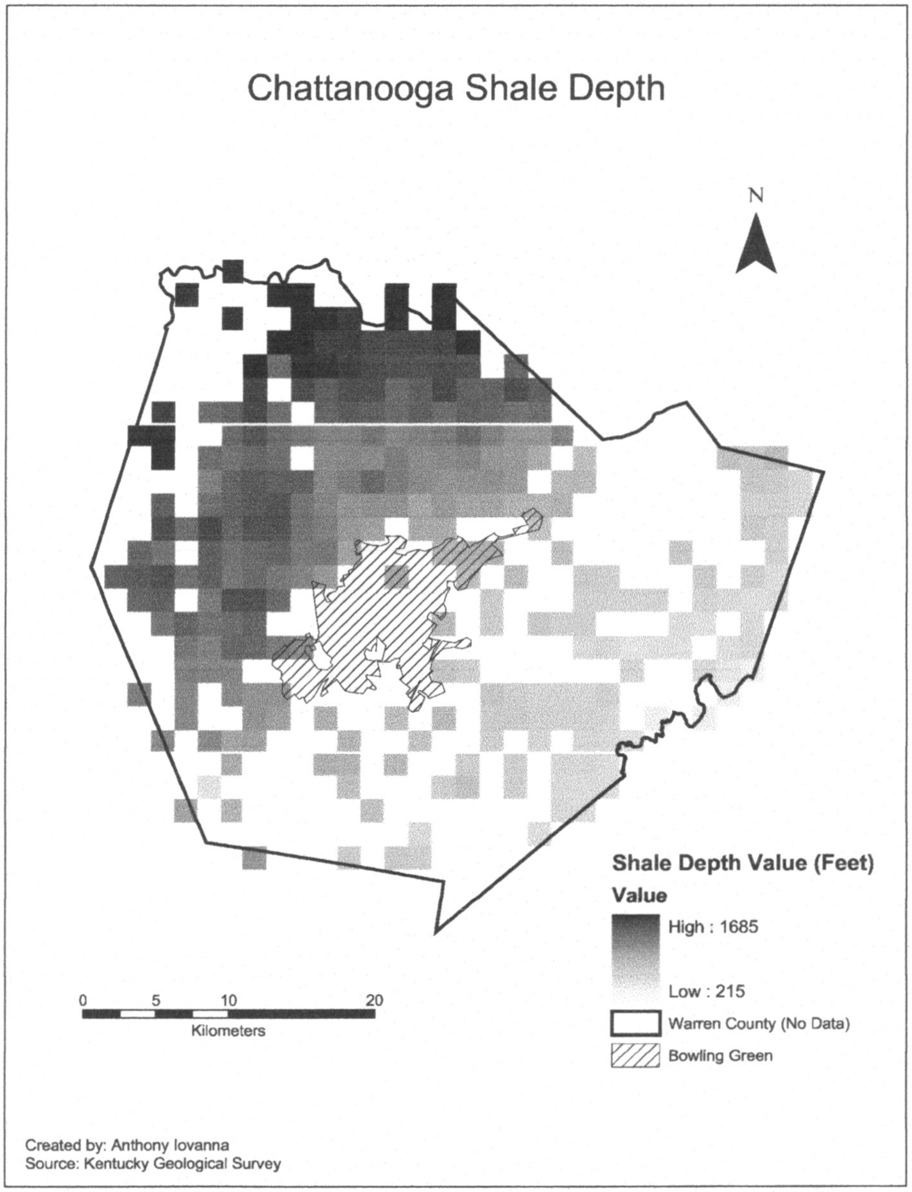

Figure 3: The depth of the Chattanooga Shale below Warren County. This map was produced using the 1.6 km by 1.6 km (one-mile by one-mile) grid. Depth to the Shale was derived from well log data. The darker areas are where the Shale is the deepest and the lighter areas are where the Shale is the shallowest. White areas are "no data". The Shale is the closest to the surface in the southeast and slopes downward to the northwest. This map was produced using Kentucky Geological Survey oil and gas well logs.

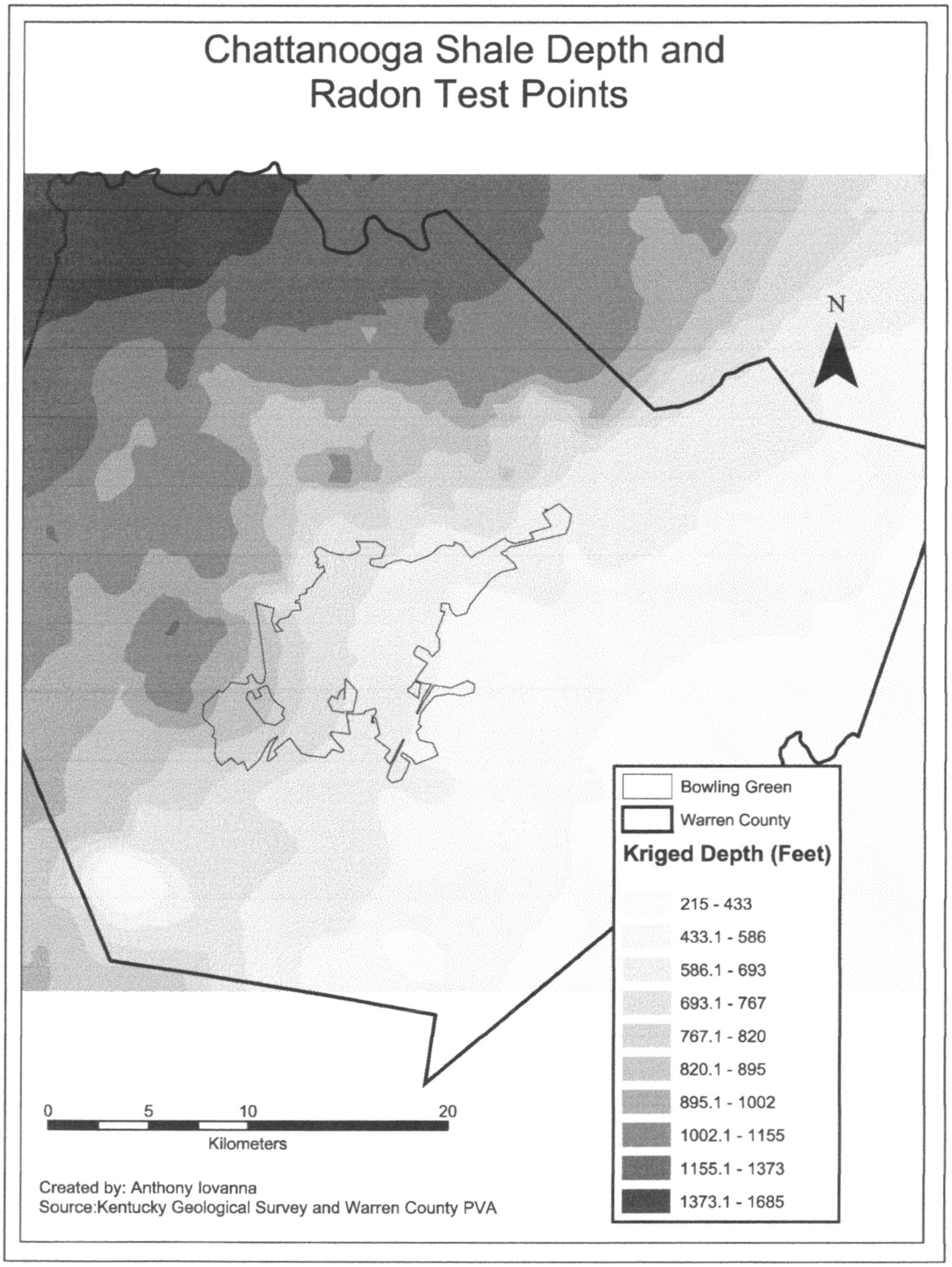

Figure 4: Kriged Chattanooga Shale depth below Warren County from Figure 3. The darker areas are where the Shale is the deepest and the lighter areas are where the Shale is the shallowest. This map was produced using Kentucky Geological Survey oil and gas well logs, and Arc GIS kriging algorithm.

Kriging is a weighted average predictor (Demirel et al., 2000; Lloyd and Atkinson, 2002) and as a geostatistical method for spatial interpolation it assumes that the spatial variation of an attribute is neither totally random nor deterministic (Chang 2004). Kriging was used by Demirel et al. (2000) to determine the thickness of the Canakci Coal Seam in Turkey. This method of interpolation was also used by Dominy and Hunt (2002) in the gold fields of Australia.

Other possible methods of interpolating the Chattanooga Shale's surface could have included using Triangulated Irregular Networks (TINs) or Splines. A Triangulated Irregular Network (TIN) is a type of interpolation data model that renders an area with non-overlapping triangles (Chang, 2004). Triangulated Irregular Networks have been used to interpolate surface elevations (Wang and Lo, 1999; Floriani et al., 2000). TINs were not used for this reason: to create a surface, a large number of evenly distributed points are needed and this type of data was not available for this study. Splines are a local interpolation method that renders a surface with a minimum amount of curvature and no standard error is produced (Chang, 2004). But splines can overestimate and/or underestimate the values of known points and thus was not an acceptable source of error.

Two hundred and seventeen residential radon measurements were obtained from a local contractor in Warren County. These points had a radon value range of 0.08 pCi/l to 222 pCi/l with a mean of 9.2 pCi/l. Eighty-four of the homes tested (39%) were above 4 pCi/l. The eighty-four test points above 4 pCi/l were kriged in Arc GIS to create a prediction surface and visually determine if there was an identifiable pattern to the location of high radon values (Figure 5). The krige predicts small pockets of high radon levels in the southern and eastern sections of Bowling Green. However, these predicted krige values are due to the influence of three extreme outliers in these areas. In the outer areas of the krige there were not enough test points above 4 pCi/l to render an accurate image. The proximity to clusters of points gives a more accurate image of predicted radon values.

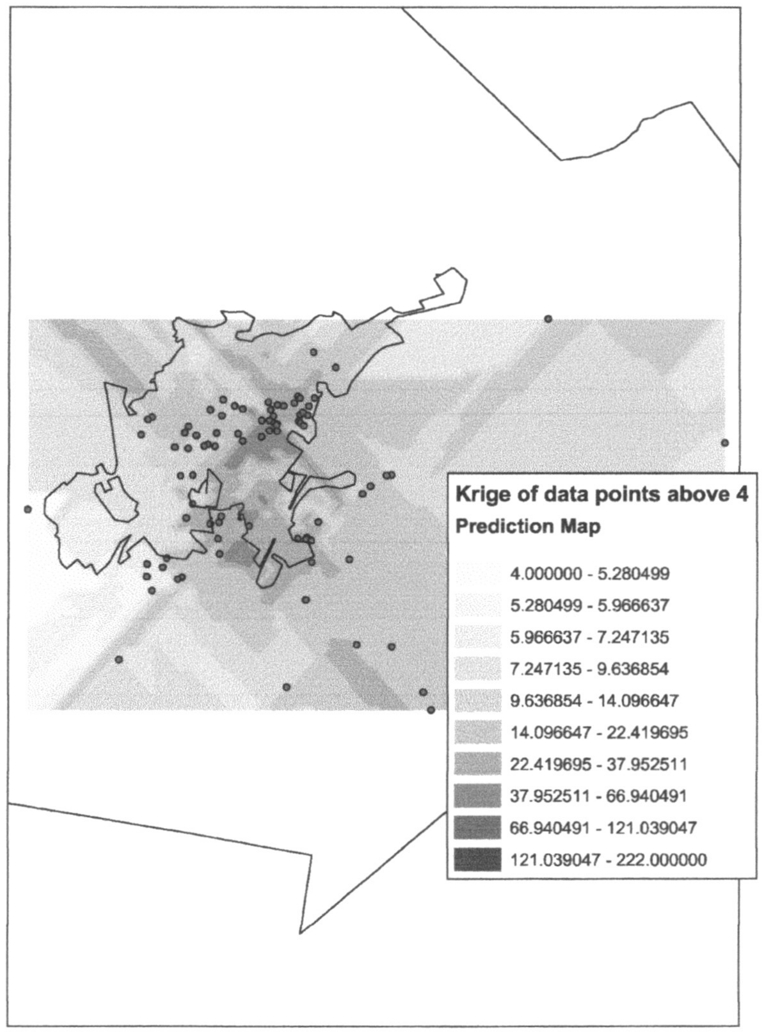

Figure 5: Krige of the eighty-four test points above 4 pCi/l. The krige does not extend outside of the Warren County boundary, the black outline. The majority of the high radon levels are found within the City of Bowling Green, represented by the black outline in the center of the figure. The legend indicates picocurie value range for a given grey shade.

Socio-economics of Warren County

As a means to better direct this study, annual household incomes needed to be determined. Income data was hypothesized to give information on home quality and size. Warren County was divided into three income groups using US Census Tract Block Groups (Taquino et al., 2002; US Census Bureau, 2000). The first income group is the percentage of households in each block group with incomes below 25,000 dollars per year (Figure 6). The second showed the percentage of households in each block group that were between 25,000 - 75,000 dollars per year (Figure 7). The third income group showed the percentage of households above 75,000 dollars per year (Figure 8) (U.S. Census Bureau, 2000). This analysis allowed the determination that most of the radon measurements were conducted in higher income areas of Warren County (Figure 9).

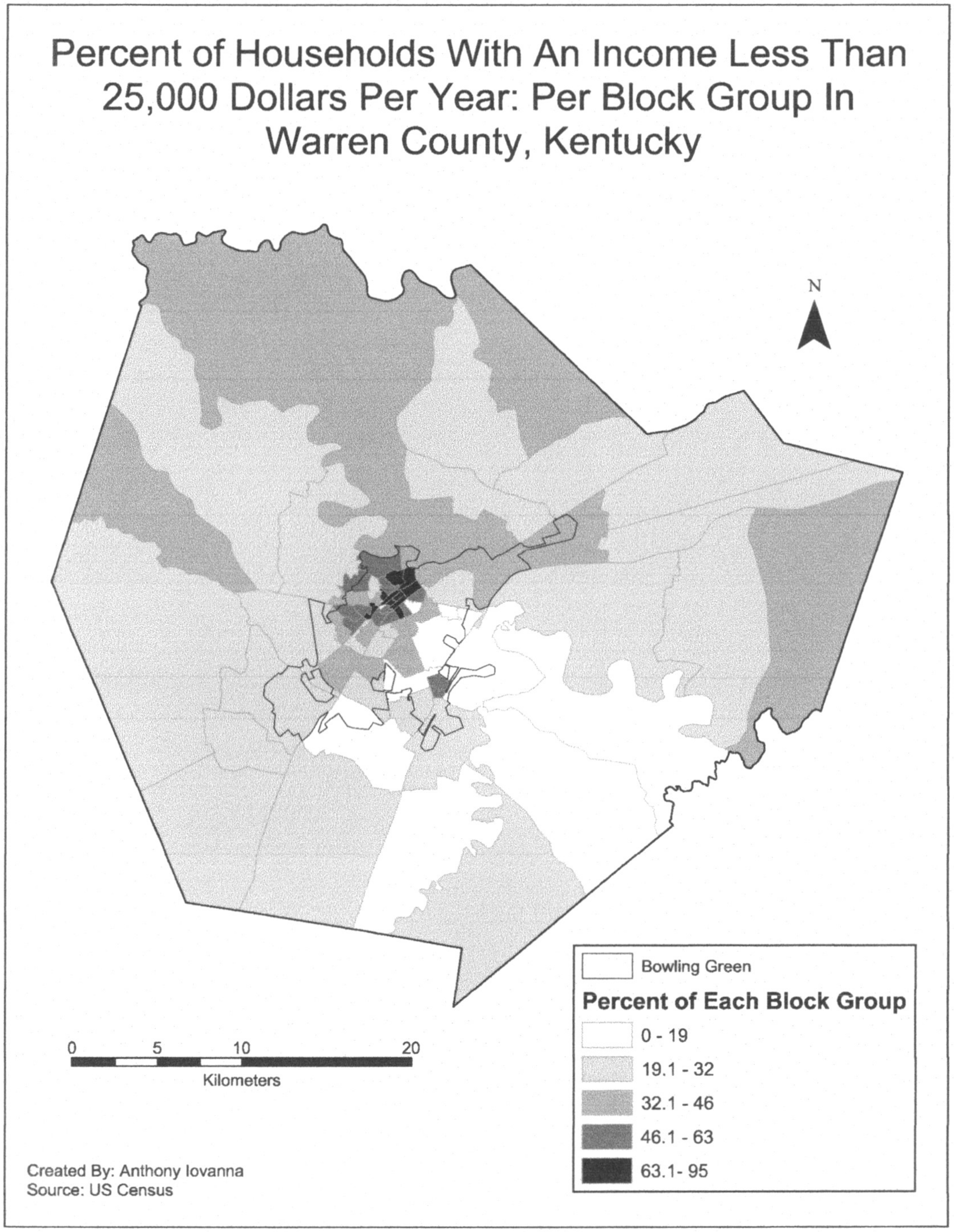

Figure 6: Percentage of households in each census block group that had an annual income below 25,000 dollars. The block groups that have a majority of households below 25,000 dollars per year are located near the center of the county and specifically in the city core of Bowling Green. From US Census Bureau (2000) data.

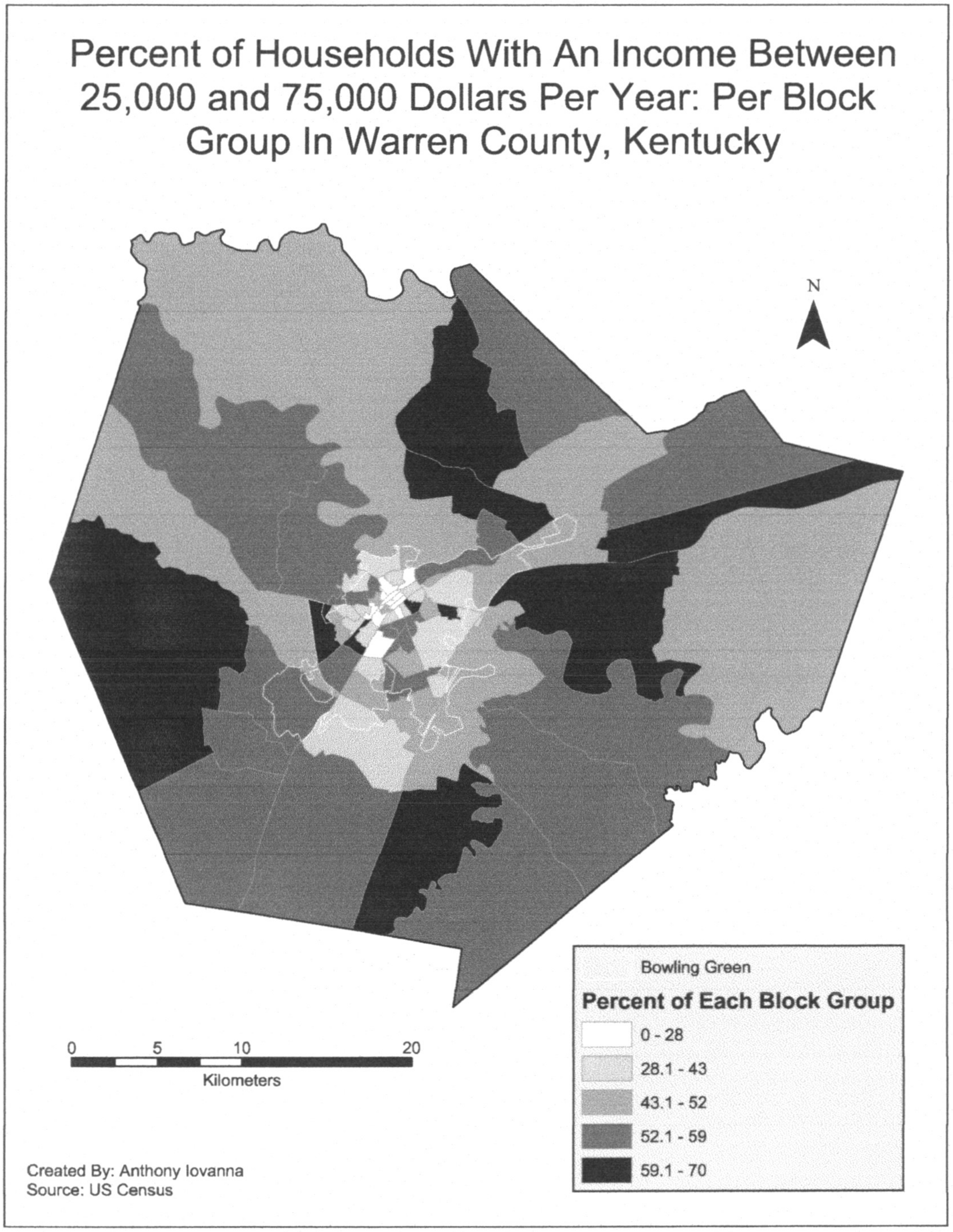

Figure 7: Percentage of households in each census block group with an annual income between 25,000 - 75,000 dollars. The block groups that have a majority of households between 25,000 and 75,000 dollars per year are located outside the City of Bowling Green. From US Census Bureau (2000) data.

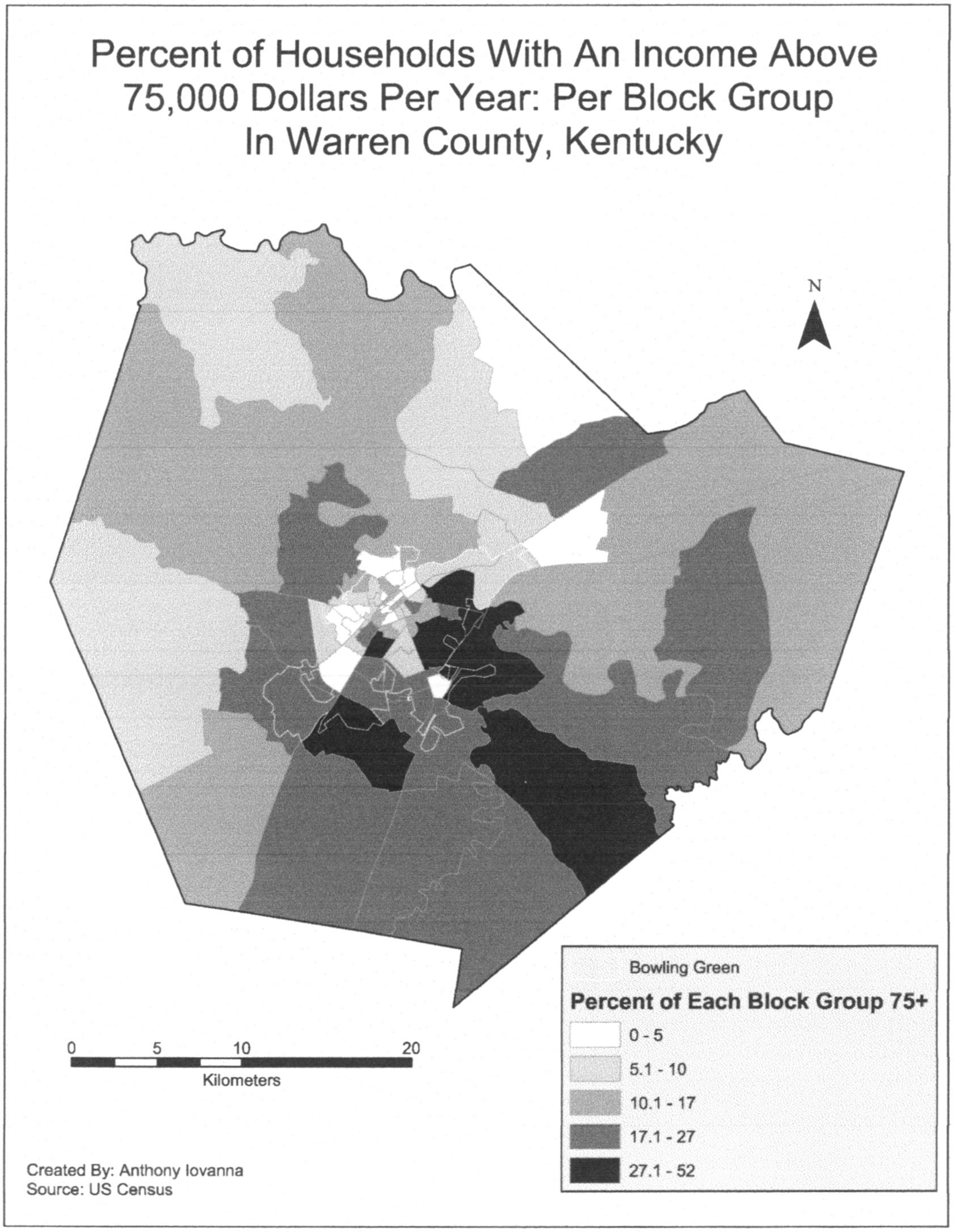

Figure 8: Percentage of households in each census block group with an annual income above 75,000 dollars. The block groups that have a majority of households above 75,000 dollars per year are located both within and outside the City of Bowling Green. However, the majority of the census block groups, with seventeen to fifty two percent of the households within the group having an annual income above 75,000 dollars, are outside the city limits of Bowling Green. From US Census Bureau (2000) data.

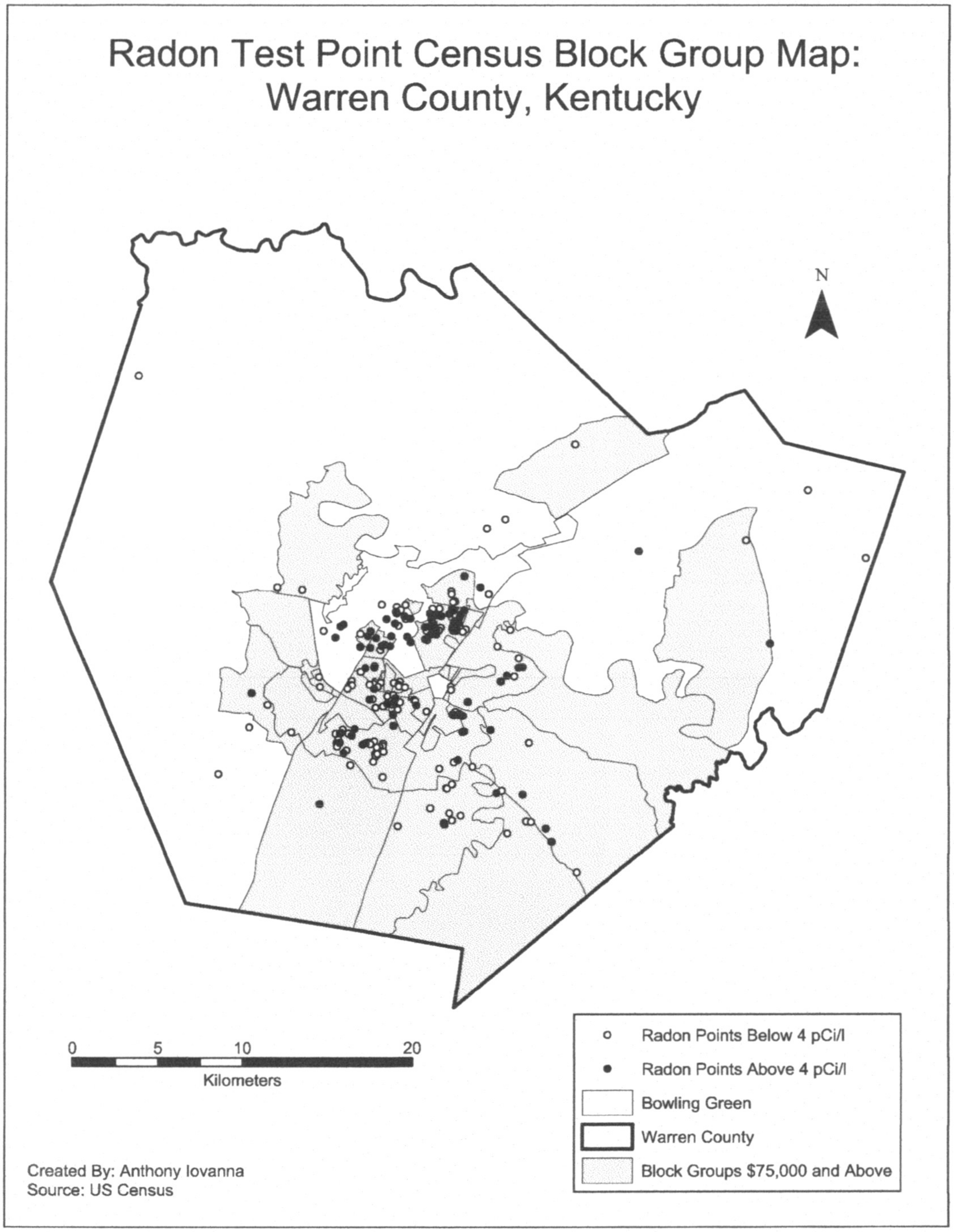

Figure 9: Census Block Groups with a majority of households having annual incomes above \$75,000 and radon test points above and below 4 pCi/l. The majority of the test locations are within the census block groups shown above. Few test locations are from areas that are not as economically prosperous. From a local radon tester and the US Census Bureau (2000).

Land Parcels

Residential characteristics were vital because they are indicators of the ease in which radon can enter the home. Land parcel data was obtained as an Arc GIS layer from the Warren County Property Value Administration (PVA). Details included in the parcel data include the square footage of the living area, the year the home was built, whether or not the home has a basement, type of heating and cooling system, ect. Specifically the PVA parcel data allowed test points that had excessive (i.e., above 4 pCi/l) radon present in the dwelling to be examined against other variables such as presence of a basement, age of the home, and square footage of the home (Table 2).

All sampled homes
All sampled homes above 4 pCi/l
All sampled homes built before 1977
All sampled homes built before 1977 above 4 pCi/l
All sampled homes built after 1977
All sampled homes built after 1977 above 4 pCi/l
All sampled homes with basements
All sampled homes basements above 4 pCi/l
All sampled homes without basements
All sampled homes without basements above 4 pCi/l
All sampled homes under 139 total square meters (1500 total square feet)
All sampled homes under 139 total square meters (1500 total square feet) above 4 pCi/l
All sampled homes above 139 total square meters (1500 total square feet)
All sampled homes above 139 total square meters (1500 total square feet) above 4 pCi/l

Table 2: These are the layers that were produced from the Warren County Property Value Administration Arc GIS layer and residential radon measurements. These layers were used to determine if a significant relationship existed between certain house characteristics and having a high radon level.

Two hundred and seventeen parcels had a radon test point value assigned to them. Of the two hundred and seventeen parcels, eighty-four of the parcels had radon levels above four pCi/l (Figure 10).

The parcels were divided into parcels less than and greater than 139 square meters (1500 square feet) of living space (Figures 11 and 12). This division was done because homes with less than 139 square meters (1500 square feet) are going to cost less, as a general rule, than homes that are greater than 139 square meters (1500 square feet). Expensive homes are likely to be more energy efficient and better sealed, thus trapping more radon. It was hypothesized that larger homes have a greater concentration of radon gas than smaller homes. There were thirty-four homes below 139 square meters (1500 square feet), and ten (29%) of these homes were above 4 pCi/l. There were one hundred and seventy-one homes that were at or above 139 square meters (1500 square feet), and seventy (41%) of these homes were above 4 pCi/l. Furthermore, since a 139 square meters (1500 square feet) home is more expensive, this data will reveal if there is an economic distribution to radon testing.

The radon test parcels also were split between non-energy efficient homes and energy efficient (Figures 13 and 14) using year built as a proxy. This procedure was followed because it was hypothesized that newer homes that included energy efficiency options in their construction that in turn tend to not let radon gas escape once it has entered the home and are better sealed. Energy efficient homes versus non-energy efficient homes were divided into two groups: homes built before 1977 and homes built after 1977. This year was used because the United States of America Department of Energy was organized in 1977 in response to the energy crisis of 1973. After the formation of the Department of Energy, measures to construct energy efficient homes were generally adopted. Thirty-nine out of two hundred and five homes were built before 1977 and twenty-five (64%) had radon levels above 4 pCi/l. One hundred and sixty-six out of two hundred and five homes were built after 1977 and fifty-five (33%) had radon levels above 4 pCi/l.

It was hypothesized that homes with basements (Figure 15) would have higher radon levels than parcels without basements (Figure 16). Ninety-five homes out of two hundred and five had basements, and forty out of ninety-five (42%) basement homes had a radon level above 4 pCi/l. There were one hundred and ten homes that did not have basements and forty (36%) of these homes were above 4 pCi/l. There was no distinction made based upon the size of the basement or the construction of the basement.

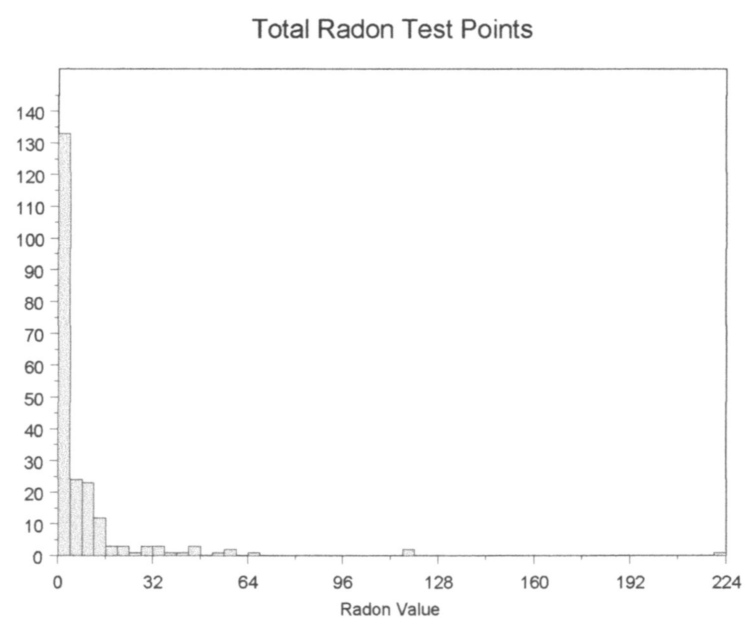

Figure 10: The total number of test points is two hundred and seventeen. The majority of test points were at or below 4 pCi/l. Eighty-four of the test points were above 4 pCi/l, and there were three extreme outliers above 4 pCi/l.

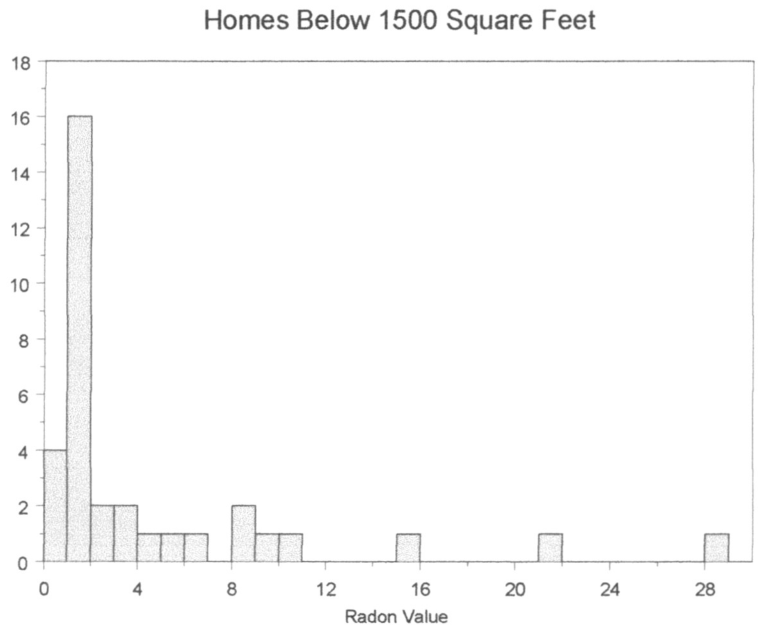

Figure 11: The total number of homes below 139 square meters (1500 square feet) that were tested for radon was thirty-four. The majority of test locations were at or below 4 pCi/l. Ten of the test points were above 4 pCi/l.

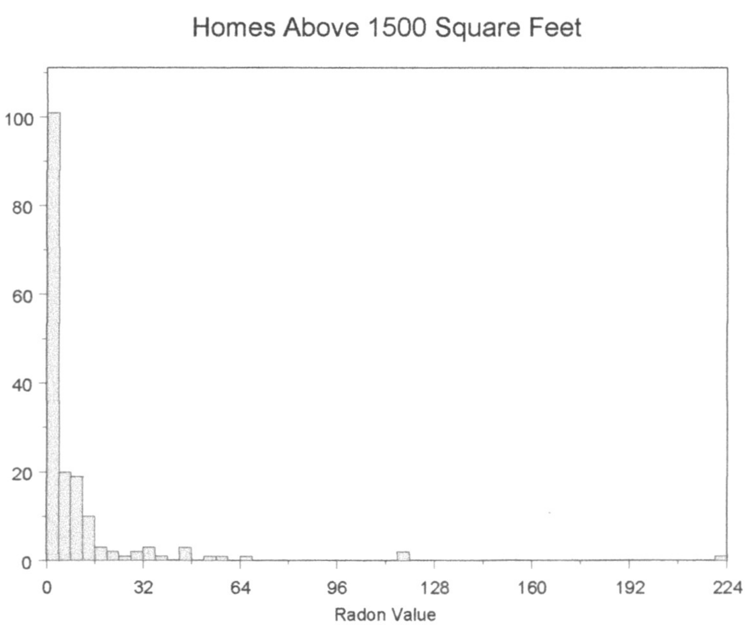

Figure 12: The total number of homes above 139 square meters (1500 square feet) that were tested for radon was one hundred and seventy one. Seventy of the test parcels were above 4 pCi/l. There are three extreme outliers above 4 pCi/l.

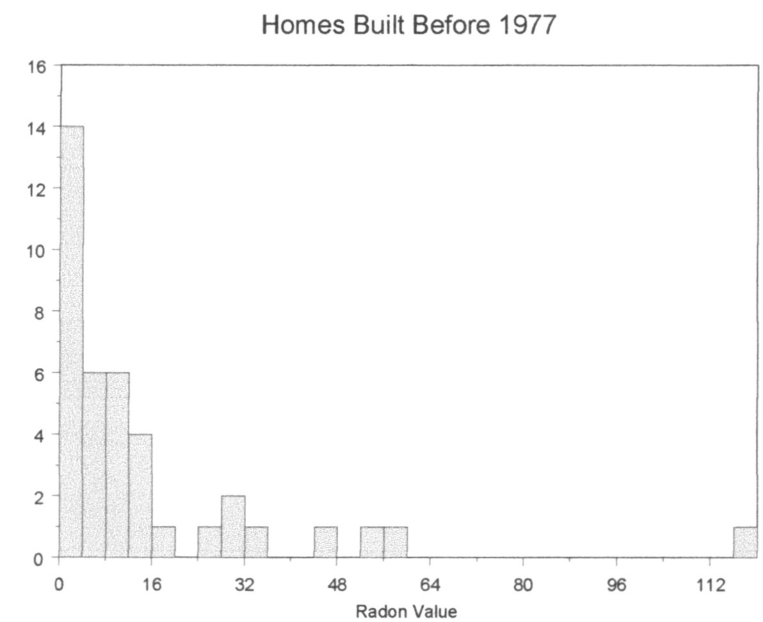

Figure 13: The total number of homes built before 1977, which were tested for radon, was thirty-nine. Twenty-five of the test parcels had levels above 4 pCi/l. There was one extreme outlier above 4 pCi/l.

Figure 14: The total number of homes built after 1977, which were tested for radon, was one hundred and sixty six. Fifty-five of the test parcels were above 4 pCi/l. There were three outliers above 4 pCi/l.

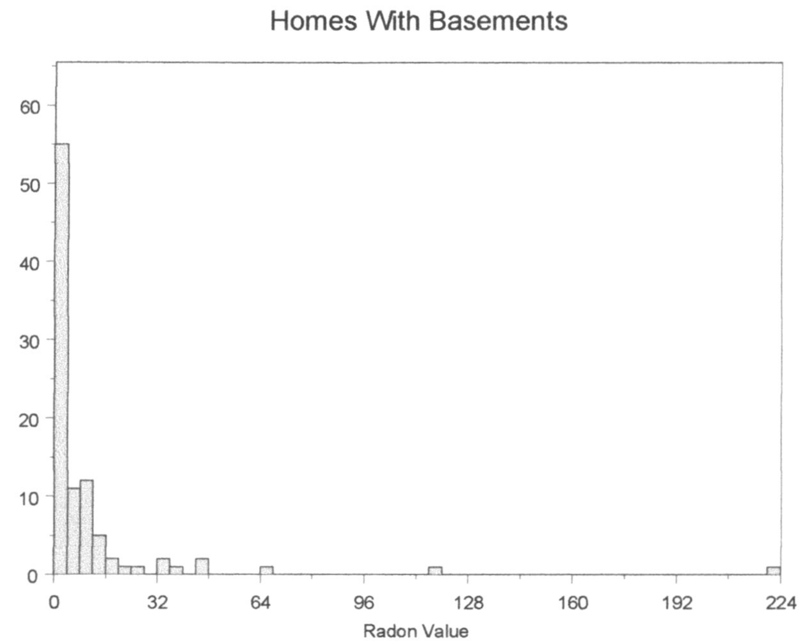

Figure 15: The total number of homes with basements that were tested for radon was ninety-five. Forty of the test parcels were above 4 pCi/l. There were three outliers above 4 pCi/l.

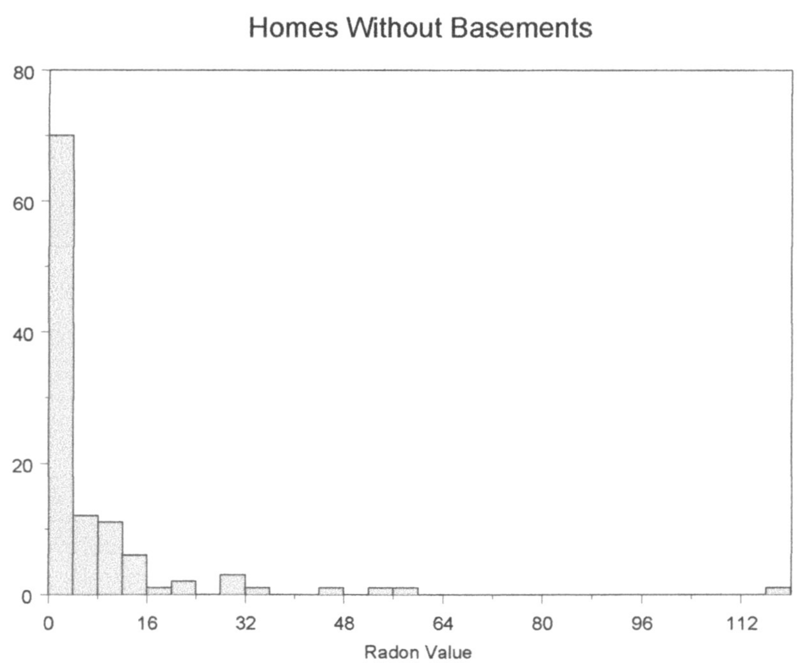

Figure 16: The total number of homes without basements that were tested for radon was one hundred and ten. Forty of the test locations were above 4 pCi/l. There was one extreme outlier above 4 pCi/l.

So as to assign a depth to Chattanooga Shale value for each of the two hundred and seventeen radon test points, the kriged depth to Chattanooga Shale GIS layer was utilized. It was hypothesized that a close proximity of radon test points to the Shale would not result in high radon levels. This test aimed to determine if the proximity of the Chattanooga Shale was a causal factor in possessing high radon levels. It allowed for each of the test points to be assigned a minimum depth to Shale and to be run statistically against ten depth classes ranging from two hundred and fifteen feet to one thousand three hundred and seventy-three feet (Figure 17).

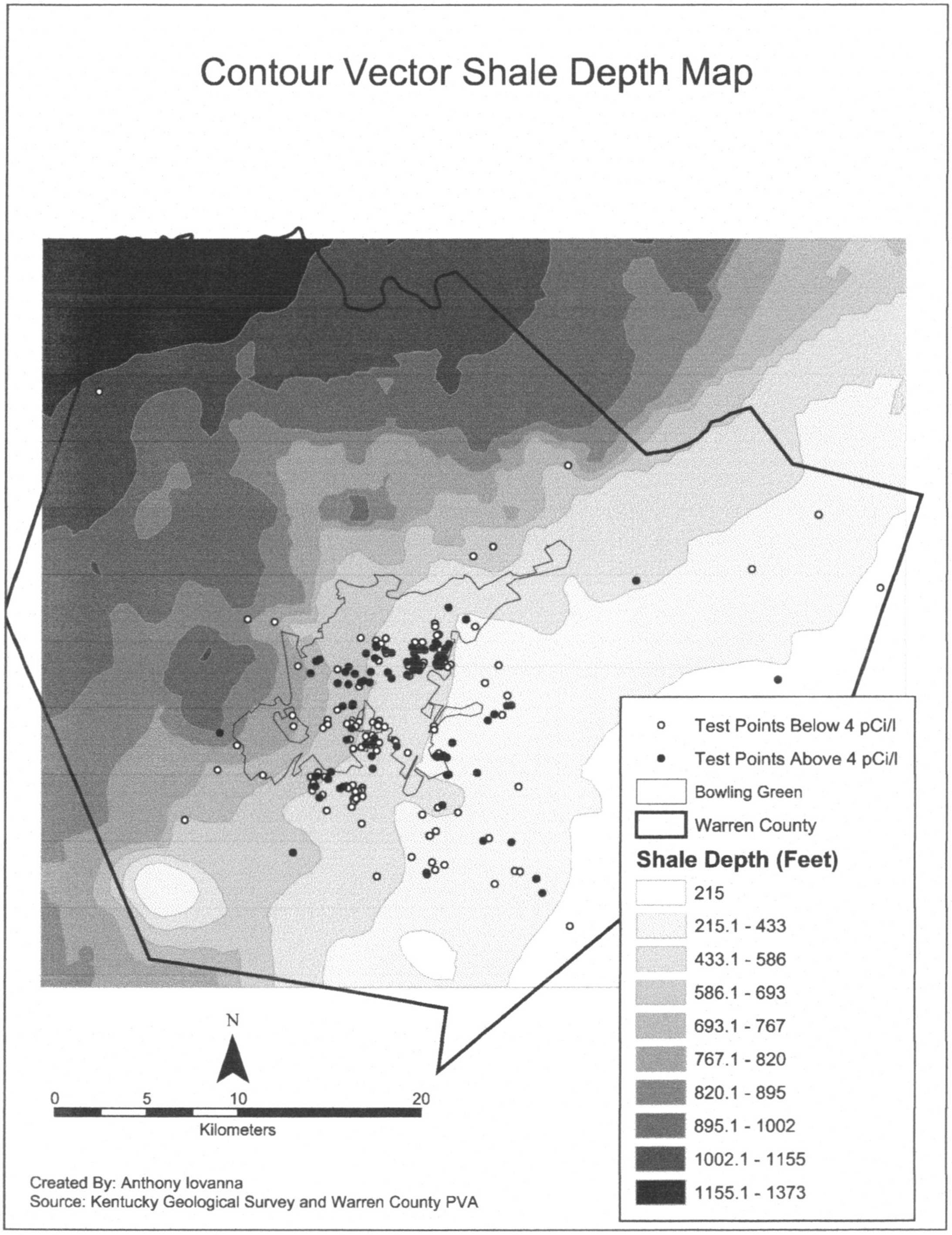

Figure 17: This shows a vector image of the "Depth to Chattanooga Shale Krige" below the surface. This map shows the minimum depth of the Chattanooga Shale below the two hundred and seventeen test locations.

Source: Kentucky Geological Survey and Warren County Property Value Administration

Statistics

Statistical analyses were used to determine if there is a significant relationship between housing characteristics and the level of indoor radon pollution present at the test locations. These analyses also determined if there is a correlation between measured radon levels and the depth of the Chattanooga Shale below the ground. The US EPA has implied that a significant relationship will exist between the proximity of the Chattanooga Shale and the high radon test values (US EPA, 1992), and this analysis will examine the validity of this assertion. This study hypothesizes that the proximity of the Shale, to the test locations, does not significantly cause high radon levels. Furthermore, a significant relationship is expected between upper income housing characteristics (large square area, newer year of home constructed and presence of a basement) and high levels of indoor radon pollution.

In order to test the hypotheses statistical hypothesis testing was used. The radon level of the test locations was being individually compared to the following factors: if the home was built before or after 1977, whether or not the home had a basement, if the home was above or below 1500 square feet, in its area, and the depth of the Chattanooga Shale below the test locations. The Two Sample Difference Tests were used to test the hypotheses. These tests include the Two Sample Difference of Means and the Two Sample Difference of Proportions Tests.

According to McGrew and Monroe (2000) the Two Sample Difference of Means Test requires that the populations be normally distributed, but that was not the case with the residential data. Although this method was not effective for examining the housing characteristics and radon levels, it was used to determine if there was a significant amount of difference between the two hundred and seventeen radon test points and the minimum depth of the Chattanooga Shale below these test points.

The Two Sample Difference of Proportions Test was used to determine if there was a significant amount of difference between the housing characteristics and the radon levels. McGrew and Monroe (2000) state that this test is designed to use categorical data that was measured on a nominal scale; and this test allows for the testing of significant differences between two independent samples when the data are binary.

Data

This study uses data that was obtained from a local radon mitigator, two hundred and seventeen radon points, as well as the Warren County Property Value Administration (PVA), house characteristics. Two hundred and five of these points had the housing characteristics available with them, and were used to determine if there was a significant relationship between high radon levels and particular housing characteristics. The two-hundred and seventeen radon test points were used to determine if there was a significant relationship between the high radon levels and the depth of the Chattanooga Shale below the surface of the study area.

The data for the house characteristics were converted into binomial data, with the aim of performing the two-sample difference of proportions test. Basement and non-basement data were entered into the statistical spreadsheet with a two representing homes that had basements and a one representing homes that did not have basements. Homes built before 1977 were assigned a one and homes built after 1977 were assigned a two. Homes that had below 139 square meters (1500 square feet) were assigned a one and homes that had above 139 square meters (1500 square feet) were assigned a two. The radon levels of the two hundred and seventeen data points were converted into binomial data, in order to perform the two-sample difference of means test and determine if there was a significant correlation between the Shale's proximity and elevated values. Homes that were below 4 pCi/l were assigned a one and homes that were above 4 pCi/l were assigned a two. The minimum depth to the Chattanooga Shale data was not converted to nominal data because there were ten classes of depth, and it did not lend itself to further simplification.

Methodology

Descriptive statistics were performed on all the radon level variables. These variables included two hundred and seventeen of the radon test values with associated binomial data on presence of a basement, year built, and home size. These descriptive statistics produced the mean, median, skewness, and the minimum and maximum radon level for all the variables (Table 3). These statistics showed that the data was being skewed by a few extreme outliers. This skewness that was present in the data is also represented in the histograms in Figures 11, 12, 13, 14, 15, 16, and 17. Due to the skewness of the data and lack of a large number of data points, the Two Sample Difference of Means Test would not be an effective method to examine the house characteristics and radon levels. The Difference of Means Test would not be effective if there were larger numbers of test locations for all the home characteristics, because the data would still be extremely skewed. The known test location data is too skewed to perform the Difference of Means Test, and obtain accurate results.

	Total Points	Mean (pCi/l)	Median (pCi/l)	Skewness	Minimum (pCi/l)	Maximum (pCi/l)
Total Radon Points	217	9.17	2.7	6.4	0.08	222
Basement Points	95	10.66	3	6.02	0.3	222
Non-basement Points	110	7.64	2.7	4.84	0.08	117
Built Before 1977	39	14.98	6.5	3.05	0.9	117
Built After 1977	166	7.65	2.4	7.77	0.08	222
Below 1500 Sqr. feet. Below 139 Sqr. meters	34	4.52	1.55	2.53	0.5	28.4
Above 1500 Sqr. feet. Above 139 Sqr. meters	171	9.94	3.1	6.09	0.08	222

Table 3: Descriptive statistics for the housing characteristics. The skewness of the test locations was determined through the application of descriptive statistics in the S-Plus statistics program.

Results

The Two Sample Difference of Proportions Test produced results that showed there was a significant amount of difference between two of the three pairs. This test showed that homes built before 1977 had significantly higher radon measurements than homes built after 1977; furthermore, homes with basements had significantly higher radon measurements than homes without basements. However, homes below and above 139 square meters (1500 square feet) of living space were not determined to be significantly different in radon values. The significance levels can be seen in Table 4. In order for a p-value to show a high level of significance the p-value must be below 0.05. The lower the p-value the higher probability that there is a relationship between two variables. A significantly larger proportion of homes have radon levels above 4 pCi/l.

Square Footage Square Meters	p-value 0.346
Year Built	p-value 0.0004
Basement and Non-basement	p-value 0.0376

Table 4: The probability that house characteristics are going facilitate high radon levels. Home built before 1977 and basement homes had a high probability of leading to high radon levels. There was not a significant probability that larger homes would have higher levels of radon.

The Two Sample Difference of Means Test was used to determine if there was a significant amount of difference between radon test levels and the minimum depth of the Chattanooga Shale below the test points. This test determined there is not a significant amount of difference between the minimum depth of the Chattanooga Shale and the radon test points. This significance level can be seen in Table 5.

Minimum Depth and Radon Level	p-value 0.4614

Table 5: There was not a significant probability that individual home's proximity to the Chattanooga Shale resulted in high residential radon levels.

Discussion

Homes size was determined to not have significant differences in radon values, although homes above 139 square meters (1500 square feet) will have a radon level above 4 pCi/l a slightly higher percentage of the time. The indication is that the assumption about larger homes being more expensive and thus better insulated was incorrect. This result was unexpected; a possible reason for this outcome is due to the lack of test points from homes that were below 139 square meters (1500 square feet).

Only thirty-four of the two hundred and five tests were conducted in homes less than 139 square meters (1500 square feet). One hundred and seventy-one of the test points came from homes that were above 139 square meters (1500 square feet). A visual representation of these points can be seen in Figure 18. Perhaps this is a function of the data set – all of the homes were expensive enough to be well insulated. Instead other risk factors, not just how well sealed a home is, should be examined.

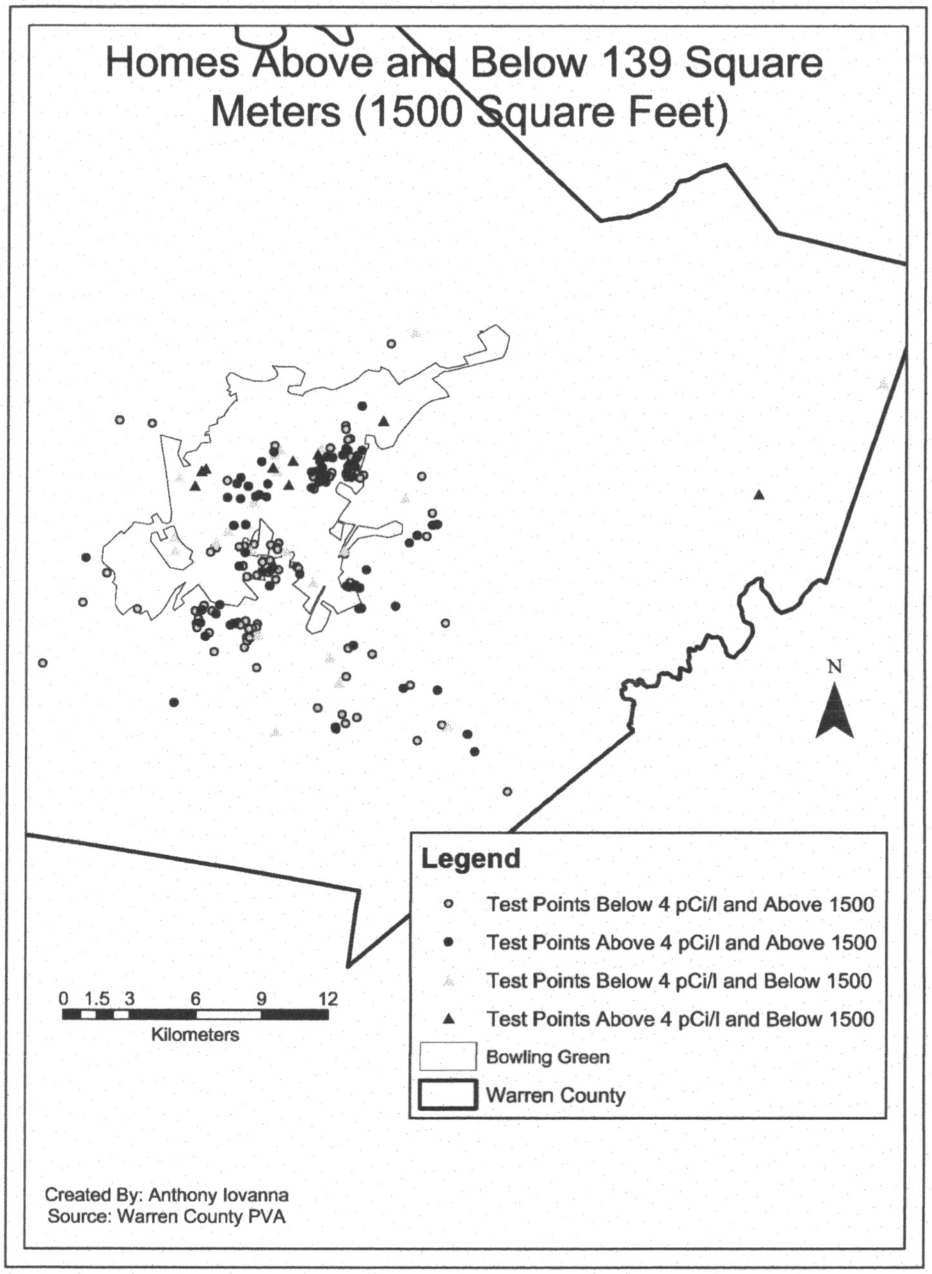

Figure 18: Radon test points for houses above and below 139 square meters (1500 square feet), Warren County and the City of Bowling Green. It also shows the number of homes above and below 4 pCi/l in both square footage categories.
Source: Warren County Property Value Administration

Homes that were built before 1977 and after 1977 had a p-value of 0.0004, a very significant difference. There was a sixty-four percent chance of having a home that was built before 1977 having a radon level above 4pCi/l. There was a thirty-two percent chance of having a home built after 1977 having a radon level above 4 pCi/l. It was expected that homes built after 1977 would have higher radon values because it was better sealed. The hypothesis about well-sealed homes having higher radon values failed. A possible explanation for this failure can be found in a Popular Mechanics magazine article from May of 1921 (Crawford, 2001). This article noted that Bowling Green had a sewer system that was made entirely by Mother Nature. It stated that homes were intentionally built over cracks and fissures in the ground so that waste from the household would flow through these cracks and fissures into the many caves beneath Bowling Green. Another possible explanation is that new homes that were built without basements were built on concrete slabs, whereas older homes that did not have basements were built over soil. Therefore the concrete slabs present in newer homes presented a barrier and restricts radon entry into the home. The test points of homes built before and after 1977 can be seen in Figure 19.

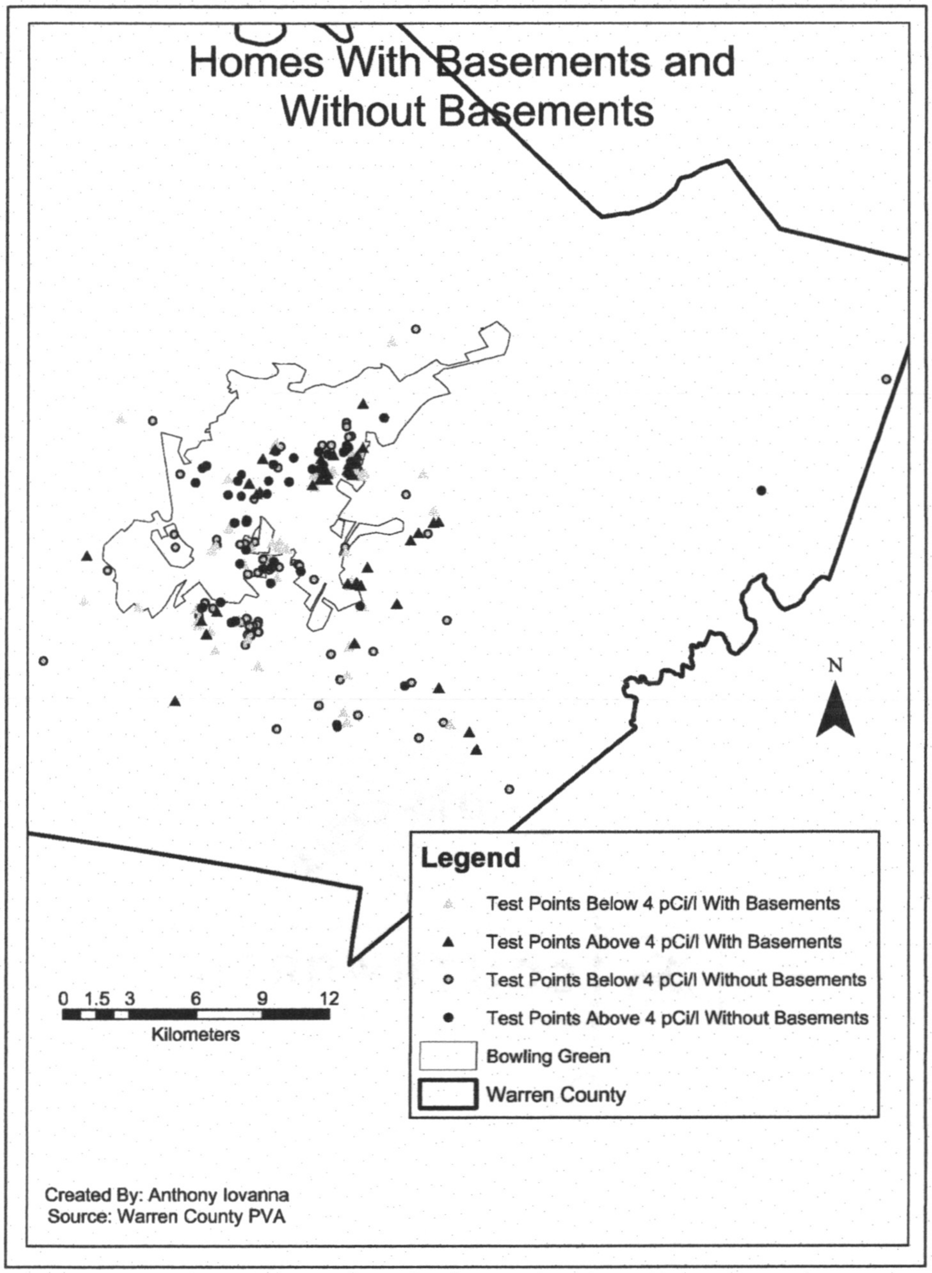

Figure 19: This map shows the distribution of test points in homes with and without basements, in Warren County and the City of Bowling Green. It also shows the number of homes above and below 4 pCi/l in basement and non-basement homes.
Source: Warren County Property Value Administration

Homes with basements and homes without basements had a p-value of 0.0376, a significant amount of difference between the pairs. There was a forty-one percent chance of a home that has a basement having a radon level above 4 pCi/l, and there was a twenty six percent chance that a home without a basement would have a radon level above 4 pCi/l. It was expected that homes with basements would have higher levels of radon than homes without basements. A possible reason for this difference is that a basement would provide a greater amount of surface area of a home below the surface and therefore allow more area for radon to enter a home (Cook and Egan, 1989). The basement and non-basement homes can be seen in Figure 20.

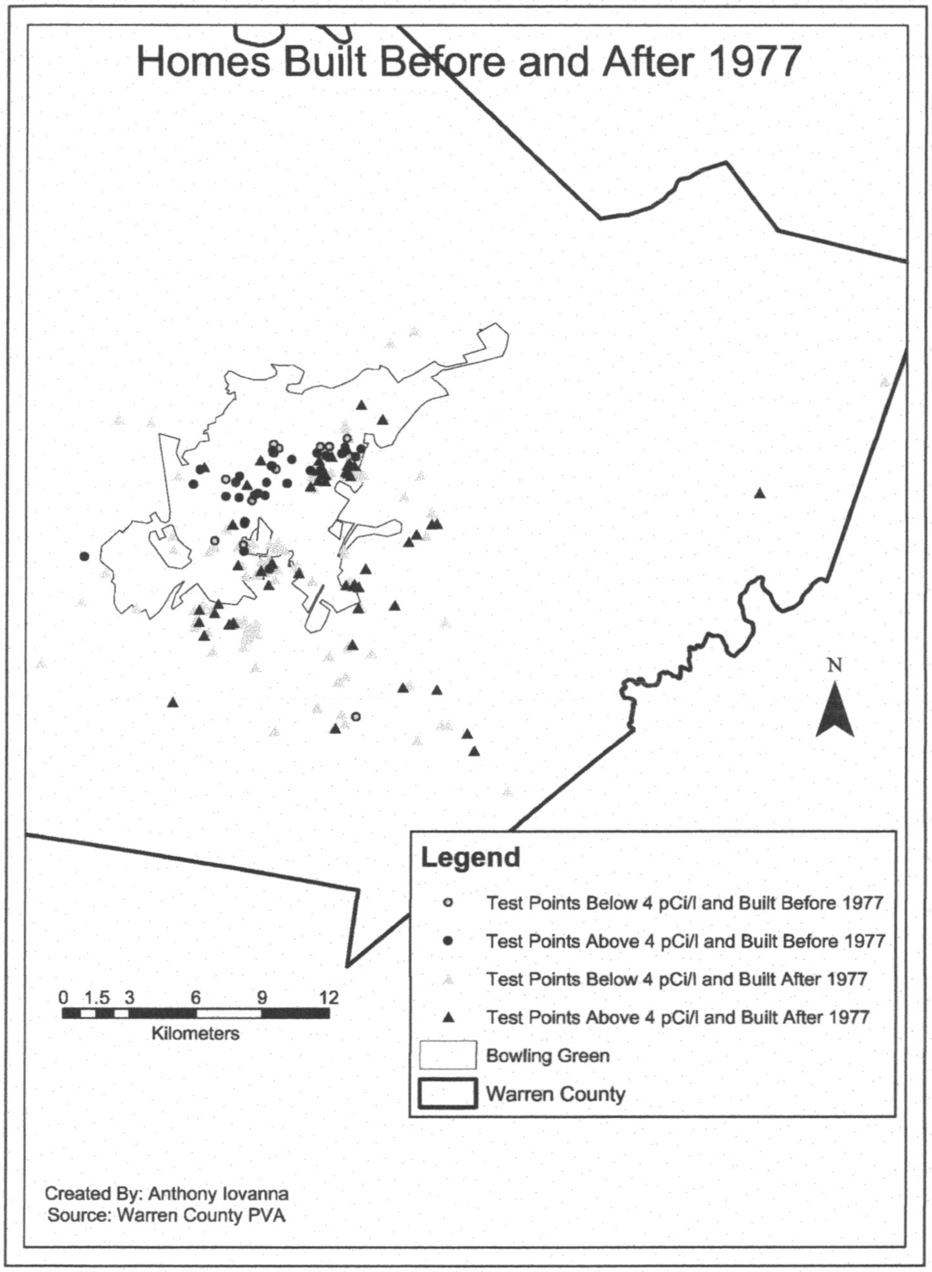

Figure 20: This map shows the distribution of test points in homes built before and after 1977, in Warren County and the City of Bowling Green. It also shows the number of homes above and below 4 pCi/l in homes built before and after 1977.
Source: Warren County Property Value Administration

There was not a significant amount of difference between radon values and the depth of the Chattanooga Shale. It was hypothesized that the test point's proximity to the Shale would not cause high levels of radon contaminations. The p-value for this pair was 0.4614 resulting in an acceptance of the hypothesized outcome. High and low radon values are present next to one another (Figure 21). This result is potentially due to karst interactions with the movement of radon from its source to the surface. Characteristics that are present in karst, such as subsurface water flows, cracks, fissures, and caves, allow radon to be transported quickly to the surface as long as there is a mechanism for that transport, i.e., cracks, caves, fissures, and subsurface water flows. The depth of a possible uranium source below the surface does not play a significant role in the location of high residential radon levels.

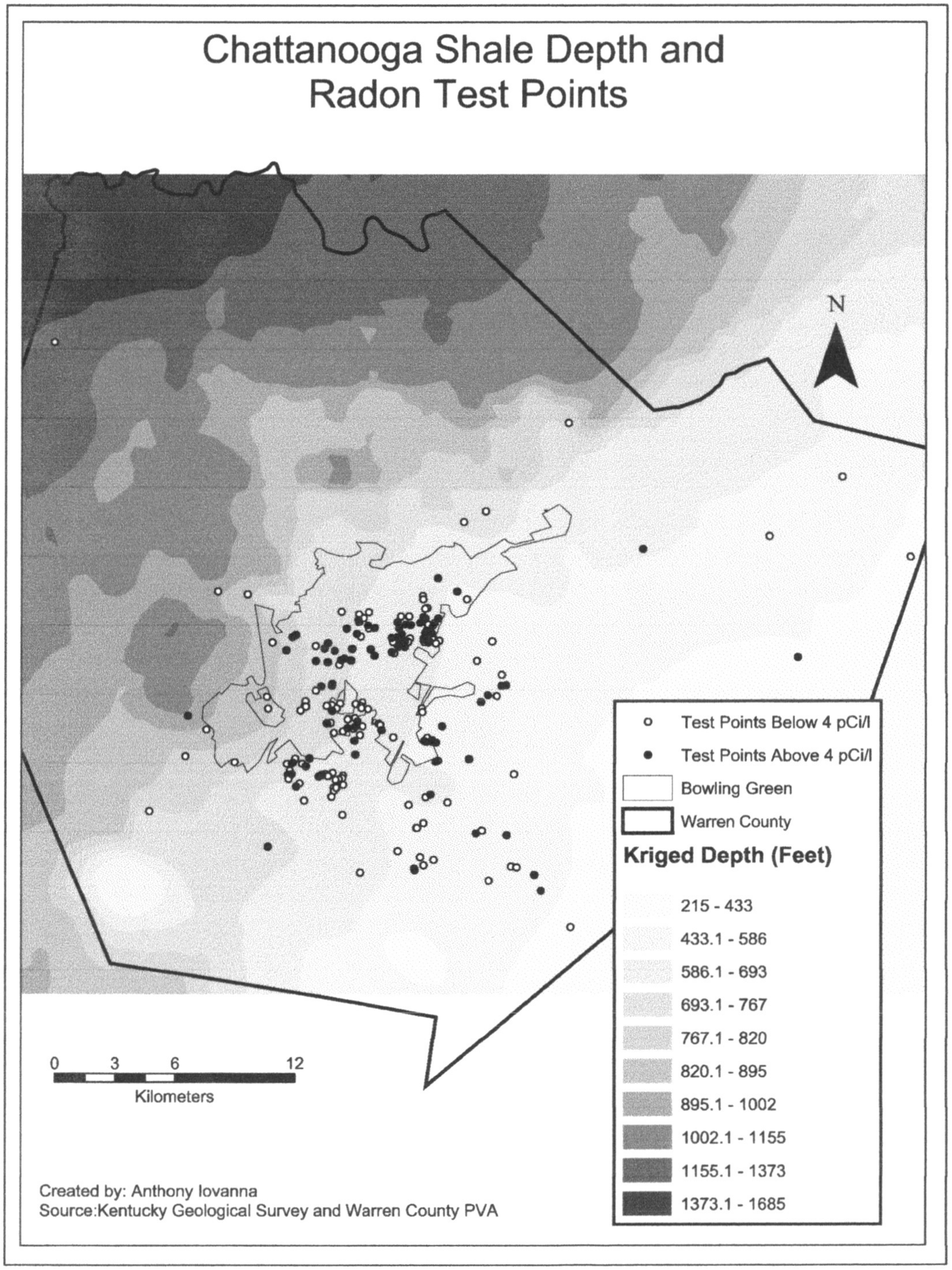

Figure 21: Radon test points and the depth to the Chattanooga Shale. Examination of this map indicates that the depth of the Shale does not appear to be the cause of high radon values. There are test locations that were below 4 pCi/l and test points that were above 4 pCi/l located next to one another but were still the same distance from the Chattanooga Shale.
Source: Kentucky Geological Survey and Warren County Property Value Administration

Conclusions

The radon test data were also combined with the Warren County income data to determine the general socio-economic status of where the radon test parcels were located. The majority of the radon tests were conducted within the census block groups that had a household income above 75,000 dollars per year. This distribution of radon test points shows that there are many areas of Warren County that are under represented in the radon test data. Future research will include a more random sampling of radon test points throughout the County.

Indoor radon is a major problem in Warren County, Kentucky, although it is an easily preventable problem. Through statistical analysis it was determined that homes with basements and homes built before 1977 have a higher probability to have radon levels above 4 pCi/l. Furthermore, homes above 139 square meters (1500 square feet) do not have a significantly higher chance of having a radon level above 4 pCi/l than do homes below 139 square meters (1500 square feet). The depth of a potential cause of the radon below the surface of Warren County, the Chattanooga Shale, does not have a significant impact on the radon levels that have been recorded in Warren County homes.

Recommendations

Subsequent studies should examine other factors that possibly influence how high radon levels are. One of these factors is the time of the year the radon test was performed. There may tend to be an increase in the number of high-test results in the colder months than in the warmer months, because radon may concentrate in higher levels during the winter months than the summer months. A reasonable explanation is that homes are more tightly closed in the winter than in the summer; as a result, radon concentrates in the home because it cannot escape from the home. Another recommendation is to examine the known subsurface flows, which are present because of the karst, in Warren County. The subsurface flows can transport radon; as the water flows, radon is aerated from the surface of the water and travels to the surface and into homes. There may be a significant relationship between the subsurface flows and high radon levels in homes. Furthermore, future studies should examine which older homes in the Warren County area were deliberately built over caves, which served as the home's sewer system, and measure the radon levels found in those homes. This further examination would reinforce the causal relationship of high levels of radon in the caves equal high levels of radon in the homes above the caves. In addition, if high levels of radon pollution are seen in a cluster of homes, where there are no mapped cave systems, there may be an unknown cave system beneath those homes. Therefore, high radon levels above ground could lead to the discovery of previously unknown caves.

This study shows that high concentrations of radon are very difficult to predict. Due to this difficulty and the human health risks it is recommended that all new home construction be built with radon resistant features incorporated into the designs. This recommendation conforms to the Building Officials and Code Administrators (BOCA) model code (renamed International Code Council); these codes can be found at www.bocai.org. Furthermore, due to the extremely high concentrations of radon that have been observed it is recommended that every real estate transaction require a radon test before a transaction can be finalized.

Radon is the second leading cause of lung cancer after cigarette smoking. Due to the number of deaths caused by radon each year it is important that the public be informed about and understand what radon is, what areas lend themselves to having high concentrations of radon, how it enters homes, what types of radon mitigation are available, and what the health effects of prolonged radon exposure are.

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Appendix Two

Radon Test Point Data

Radon Value (pCi/l)	Living Area (Square Feet)	Year Built	Basement/Non-basement
0.08	1632	1994	NONE
0.30	1548	2002	NONE
0.30	3003	1997	1/4 FINISHED
0.40	2434	1995	1/4 FINISHED
0.40	1772	1997	UNFINISHED
0.40	2510	2000	UNFINISHED
0.50	1152	1992	NONE
0.50	2029	2002	NONE
0.60	5547	1997	UNFINISHED
0.60	2160	2002	UNFINISHED
0.60	2196	1998	UNFINISHED
0.60	4219	1995	1/4 FINISHED
0.70	2740	1980	1/4 FINISHED
0.70	1880	1987	NONE
0.70	2690	1994	1/4 FINISHED
0.70	2418	1995	UNFINISHED
0.70	1485	2000	NONE
0.70	1468	2000	NONE
0.70	2321	2001	UNFINISHED
0.80	0	0	
0.80	1336	2001	NONE
0.80	4254	1999	1/4 FINISHED
0.90	1829	1995	NONE
0.90	2112	1965	NONE
0.90	2294	1978	UNFINISHED
0.90	1608	2001	NONE
0.90	2475	2000	UNFINISHED
0.90	1956	2002	NONE
1.00	2951	1999	UNFINISHED
1.00	2313	1993	UNFINISHED
1.00	2404	1998	UNFINISHED
1.10	1080	1995	NONE
1.10	2337	1994	UNFINISHED
1.10	1050	1960	NONE
1.10	1484	1987	UNFINISHED
1.10	2852	1997	UNFINISHED
1.10	3250	1997	NONE
1.20	1298	1905	NONE
1.20	3136	1988	1/4 FINISHED
1.20	2836	2000	1/4 FINISHED
1.20	3175	1999	UNFINISHED
1.20	1991	1992	NONE
1.20	1155	1996	NONE
1.20	3272	1994	1/4 FINISHED

1.20	1594	1994	NONE
1.20	1515	2002	NONE
1.20	1182	1993	NONE
1.20	1688	2001	NONE
1.20	1224	2002	NONE
1.30	752	1935	NONE
1.30	2667	1998	NONE
1.30	1457	1996	NONE
1.30	1300	1948	NONE
1.30	1329	1985	UNFINISHED
1.40	1576	2000	NONE
1.40	4156	1991	NONE
1.40	1444	1987	ALL FINISHED
1.50	2143	1979	NONE
1.50	2402	1985	NONE
1.50	1065	1997	NONE
1.50	2108	1987	1/4 FINISHED
1.50	2627	2001	UNFINISHED
1.50	2061	1999	NONE
1.60	2292	1905	UNFINISHED
1.60	896	1935	NONE
1.60	2757	2000	1/4 FINISHED
1.60	3223	2001	1/4 FINISHED
1.60	2276	1997	UNFINISHED
1.60	3037	2001	1/4 FINISHED
1.60	1527	1999	NONE
1.60	1613	1998	NONE
1.70	1524	1971	NONE
1.70	2201	2000	NONE
1.70	1139	1979	NONE
1.70	2824	1999	NONE
1.70	1641	1974	NONE
1.80	0	0	
1.80	1287	1954	NONE
1.80	2134	1997	1/4 FINISHED
1.80	2170	1996	NONE
1.80	3816	1999	NONE
1.80	1552	1997	NONE
1.80	1790	2000	NONE
1.90	3604	1978	1/4 FINISHED
1.90	0	0	
2.00	1331	1999	UNFINISHED
2.00	1640	1999	NONE
2.00	1318	2002	NONE
2.10	2804	1994	1/4 FINISHED
2.20	1662	2001	UNFINISHED
2.20	2544	1987	1/4 FINISHED
2.20	2524	1999	UNFINISHED
2.30	0	0	
2.30	1779	1987	1/4 FINISHED

2.30	3189	1979	UNFINISHED
2.30	0	0	
2.40	0	0	
2.40	3717	1996	NONE
2.40	2248	1995	1/4 FINISHED
2.40	2341	2003	NONE
2.50	2015	1964	NONE
2.50	2679	2000	UNFINISHED
2.50	1508	1997	NONE
2.50	1607	1994	NONE
2.60	1698	1984	NONE
2.60	2802	1995	1/4 FINISHED
2.70	0	0	
2.70	2246	1875	NONE
2.70	1662	1999	NONE
2.80	2203	1997	UNFINISHED
2.90	2032	1981	NONE
3.00	1737	1988	UNFINISHED
3.10	3330	1977	1/4 FINISHED
3.10	1516	1982	NONE
3.10	1940	1995	NONE
3.10	2793	1988	NONE
3.20	2357	1985	NONE
3.20	1648	1993	NONE
3.30	4284	1997	1/4 FINISHED
3.30	2076	1982	NONE
3.30	1851	1996	NONE
3.30	1578	1990	NONE
3.40	0	0	
3.40	2016	1990	NONE
3.50	3474	1964	ALL FINISHED
3.60	4468	1991	1/4 FINISHED
3.70	1992	1985	NONE
3.70	2160	1987	SEE CARD
3.70	1147	1988	NONE
3.80	3448	1993	1/4 FINISHED
3.90	1232	1975	NONE
3.90	1875	1995	NONE
3.90	2697	2002	UNFINISHED
4.00	2192	1995	NONE
4.00	2796	1978	UNFINISHED
4.20	1352	1977	NONE
4.20	2016	1976	UNFINISHED
4.20	3042	1996	UNFINISHED
4.50	2842	1992	UNFINISHED
4.60	2507	1958	NONE
5.00	3355	1991	1/4 FINISHED
5.00	2241	1995	UNFINISHED
5.10	2172	1986	NONE
5.30	3595	1950	NONE

5.40	3319	1998	UNFINISHED
5.40	3394	1993	UNFINISHED
5.40	1806	1998	NONE
5.50	3610	2002	UNFINISHED
5.70	0	0	
5.70	2911	2001	UNFINISHED
5.80	1179	1960	NONE
5.80	3086	1987	NONE
6.40	1986	1956	NONE
6.50	1430	1970	NONE
6.50	1816	1980	NONE
7.10	2170	1992	1/4 FINISHED
7.20	2618	2000	NONE
8.10	1152	1988	NONE
8.10	1437	1980	NONE
8.80	2176	1915	UNFINISHED
8.90	3238	1992	UNFINISHED
9.00	1860	1983	NONE
9.10	2780	1994	1/4 FINISHED
9.10	2639	2001	UNFINISHED
9.20	2750	1994	1/4 FINISHED
9.20	1943	1975	NONE
9.30	2950	1994	UNFINISHED
9.40	3427	2001	1/4 FINISHED
9.60	1562	2002	NONE
9.80	1156	1932	NONE
9.90	2645	1995	NONE
10.00	1758	1969	NONE
10.20	1766	1997	NONE
10.40	880	1954	NONE
10.60	3524	1969	UNFINISHED
10.60	1598	2003	NONE
11.10	2580	1991	1/4 FINISHED
11.10	4446	1993	1/4 FINISHED
11.10	2350	1993	1/4 FINISHED
11.30	2145	1987	UNFINISHED
12.20	2600	1995	1/4 FINISHED
12.40	3270	1949	UNFINISHED
12.70	3747	1988	1/4 FINISHED
12.80	0	0	
12.90	2316	1986	UNFINISHED
13.10	4777	1994	1/4 FINISHED
13.60	2160	1982	NONE
13.60	1515	1991	NONE
13.80	3442	1996	NONE
14.30	1848	1958	NONE
15.00	1425	1968	NONE
15.40	1581	1961	NONE
16.70	1906	1947	NONE
18.20	2494	1977	1/4 FINISHED

18.70	1590	2000	UNFINISHED
20.30	1789	2001	NONE
21.80	1199	1977	NONE
22.00	2248	1993	1/4 FINISHED
24.10	1914	1973	1/4 FINISHED
28.40	1428	1907	NONE
29.10	1673	1940	NONE
30.30	2171	1977	NONE
32.50	4472	1999	1/4 FINISHED
33.70	2711	2002	1/4 FINISHED
34.60	4137	1976	NONE
37.80	2296	1990	UNFINISHED
41.20	0	0	
44.50	1799	1980	NONE
46.70	3826	1990	1/4 FINISHED
47.00	2914	1970	1/4 FINISHED
55.90	3100	1964	NONE
56.10	1797	1956	NONE
58.40	0	0	
64.70	3330	1978	UNFINISHED
116.00	2633	2000	UNFINISHED
117.00	1682	1968	NONE
222.00	4246	1997	UNFINISHED